NASA TECHNICAL MEMORANDUM

NASA TM X-64678

A PRELIMINARY INVESTIGATION OF THE ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEMS (EC/LSS) FOR ANIMAL AND PLANT EXPERIMENT PAYLOADS

By Hubert B. Wells
Program Development

May 15, 1972

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. TM X-64678	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE A Preliminary Investigation of the Environmental Control and Life Support Subsystems (EC/LSS) for Animal and Plant Experiment Payloads		5. REPORT DATE May 15, 1972
		6. PERFORMING ORGANIZATION CODE PD-DO-MC
7. AUTHOR(S) Hubert B. Wells		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by the Crew Systems Branch, Propulsion and Mechanical Systems Division
Preliminary Design Office, Program Development

16. ABSTRACT

This report presents a preliminary study of the environmental control and life support subsystems (EC/LSS) necessary for an earth orbital spacecraft to conduct biological experiments. The primary spacecraft models available for conducting these biological experiments are the Space Shuttle and Modular Space Station. The experiments would be housed in a separate module that would be contained in either the Shuttle payload bay or attached to the Modular Space Station. This module would be manned only for experiment-related tasks, and would contain a separate EC/LSS for the crew and animals.

Metabolic data have been tabulated on various animals that are considered useful for a typical experiment program. The minimum payload for the 30-day Space Shuttle module was found to require about the equivalent of a one-man EC/LSS; however, the selected two-man Shuttle assemblies will give a growth and contingency factor of about 50 percent. The maximum payloads for the Space Station mission will require at least a seven-man EC/LSS for the laboratory colony and a nine-man EC/LSS for the centrifuge colony. There is practically no room for growth or contingencies in these areas.

17. KEY WORDS Life Sciences, Animal and Plant EC/LSS, Crew EC/LSS, Atmospheric Supply and Pressurization, Atmospheric Purification, Water Management, Waste Management, Animal Expendables	18. DISTRIBUTION STATEMENT Unclassified - unlimited STAR Announcement Herman E. Thomason Erich E. Goerner Director, Preliminary Design Office

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	68	$ 3.00

MSFC - Form 3292 (May 1969)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Concluded)

TECHNICAL MEMORANDUM X-64678

A PRELIMINARY INVESTIGATION OF THE ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEMS (EC/LSS) FOR ANIMAL AND PLANT EXPERIMENT PAYLOADS

SECTION I. INTRODUCTION

This study was undertaken to serve as a preliminary environmental control and life support subsystems (EC/LSS) guide for the space biology payload definition and integration study, performed under contract (NAS8-26468) by the General Dynamics Corporation (GDC) Convair Division. The GDC program will develop payload definition concepts and preliminary designs in space biology applicable to manned orbiting Space Stations. A program change was made to include the total life sciences area, i.e., space biology, medical research, manned system integration, and life support/protective systems.

The NASA/GDC "ordered payloads" were those selected to perform research in primates, vertebrates, invertebrates, plants, cells and tissues, or any desired combination of research areas. A series of computer runs was made of the functions and equipment inventories of the various available biological experiments to define a family of space biology payloads. The selected payloads (maximum-middle-minimum) were the result of a joint effort among GDC, NASA/MSFC, and ARC.

The details of the maximum, middle, and minimum payload definitions are shown in Table 1. The minimum experiment payloads are indicated for the 7-day and 30-day Shuttle modules and those termed as flights of opportunity. The middle payloads are committed to the 90-day Shuttle module, and the maximum payloads are reserved for long-term resupplied Space Station flights, such as the Option IV Modular Space Station (Fig. 1).

This study concentrates on payload extremes by selecting a suitable EC/LSS for the 30-day minimum Shuttle payload and the maximum experiment module payload. For experiment purposes, the 30-day Shuttle payload will utilize 2 Macaque monkeys, 32 rats, 16 Marigold plants, and 2 incubators for cells, tissues, and invertebrates (assorted experiment-peculiar packages). The maximum experiment payload will contain 2 Macaque monkeys, 1 chimpanzee, 256 rats, 144 Marigold plants, and 7 incubators for cells, tissues, and invertebrates in the laboratory portion only. The centrifuge portion of

TABLE 1. PAYLOAD FUNCTIONAL CAPABILITIES

	Mission	E	Criticality	Mode	Organism (Sizing)	No. Lab.	No. Cent.	Cage Modules Lab.	Cage Modules Cent.	Candidate Organism Payloads (Substitution Factors Below)
Minimum	Shuttle Module (7-day)	M	0	O	Primates	0	0		N/A	
		V	1	A	Rats	16	0	1		8 rats, 16 mice, 1 rabbit
		P	1	A	Marigolds	16	0	1		8 Marigolds, 8 seed packages, 12 Tradescantia
		I	1	A	Incubator	1	0	1		Assorted experiment-peculiar packages.
		C	1	A	Incubator	1	0	1		Assorted experiment-peculiar packages.
	Shuttle Module (30-day)	M	2	S	Primates	2	0		N/A	Special holding 2 Macaques
		V	2	S	Rats	32	0	2		16 rats, 32 mice, 2 rabbits
		P	2	S	Marigolds	16	0	1		16 Marigolds plus assorted seeds and plants
		I	2	S	Incubator	1	0	1		Assorted experiment-peculiar packages.
		C	2	S	Incubator	1	0	1		Assorted experiment-peculiar packages.
	Flights of Opportunity	M	1	M	Primates	2	0			Special holding 2 Macaques
		V	2	M	Rats	64	0	4		32 rats, 32 mice, 6 rabbits
		P	1	M	Marigolds	64	0	4		32 Marigolds plus assorted seeds and plants
		I	1	M	Incubators	1	0	1		Assorted experiment-peculiar packages.
		C	1	M	Incubators	1	0	1		Assorted experiment-peculiar packages.
Middle	Shuttle Module (90-day)	M	3	M	Primates	2	0		N/A	Special holding 2 Macaques
		V	3	M	Rats	128	0	8		64 rats, 64 mice, 24 rabbits/GP
		P	2	M	Marigolds	128	0	8		64 Marigolds plus assorted seeds and plants
		I	2	M	Incubators	2	0	2		Assorted experiment-peculiar packages.
		C	2	M	Incubators	2	0	2		Assorted experiment-peculiar packages.
Maximum	Maximum (Nominal)	M V P I C	TBD	TBD	Primates Rats Marigolds Incubator Incubator	TBD	TBD	TBD	TBD	TBD
	Maximum (Maximum)	M	3	M	Primates	3	3			2 chimpanzees, 4 Macaque (lab. 50%, cent. 50%)
		V	3	M	Rats	256	352	16	22	256 rats, 256 mice, 70 rabbits/GP
		P	3	M	Marigolds	144	144	9	9	256 Marigolds plus assorted seeds and plants
		I	3	M	Incubator	3	3	3	3	Assorted experiment-peculiar packages.
		C	3	M	Incubator	4	4	4	4	Assorted experiment-peculiar packages.

LEGEND

Element (E) M = Primates V = Vertebrates P = Plants I = Invertebrates C = Cells and Tissues

Criticality 1 = Mandatory 2 = Highly Desirable 3 = Desired (3 = 3 + 2 + 1 2 = 2 + 1)

Mode M = Manual S = Semiautomatic A = Automatic (M = M + S + A S = S + A)

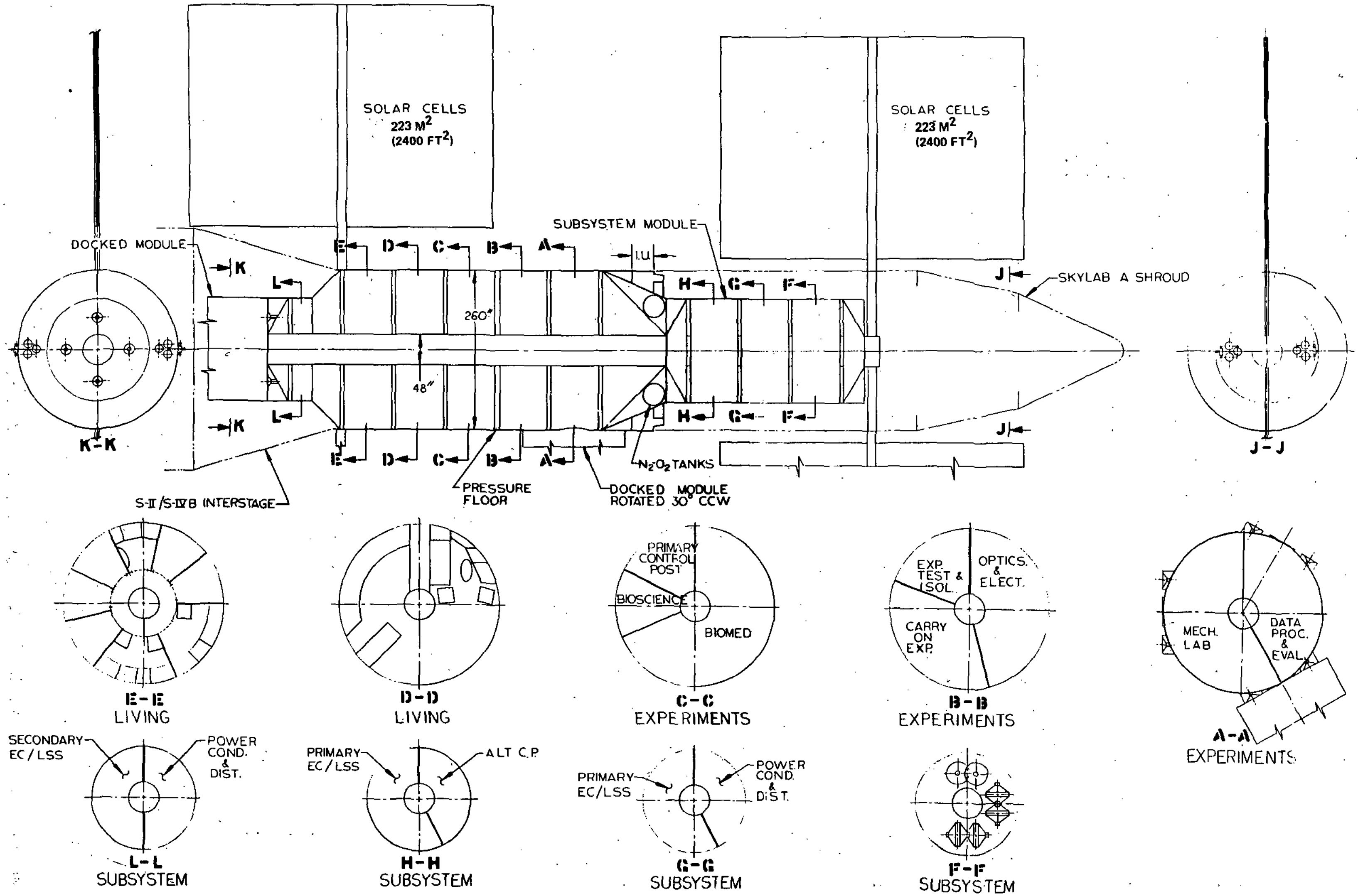

Figure 1. Option IV Modular Space Station.

this payload is identical to that of the laboratory, except that 96 more rats are added.

A survey was made to define a group of assemblies and components suitable for fulfilling the EC/LSS requirements for the payloads stated. To minimize cost, existing manned assemblies should be used to fulfill the animal EC/LSS requirements. EC/LSS assemblies provided for the Shuttle crew compartment are excellent candidates for the minimum payload; whereas the maximum payload EC/LSS assemblies may be drawn from the Modular Space Station effort. No attempt has been made to define a thermal control assembly for these payloads, manned payload included.

SECTION II. CREW ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM

To minimize experiment module contamination, separate EC/LSS's are required for both the crew and animals. The EC/LSS's as stated in this report for the Space Shuttle crew compartment and Modular Space Station are designed to sustain a crew of two and six men, respectively. EC/LSS's for additional crewmen or passengers are provided at the expense of the Shuttle payload. The EC/LSS for the Shuttle is designated as an open-loop system (open O_2 and H_2O); whereas the EC/LSS selection for the Modular Space Station [1] is known as a partially-closed-loop. This signifies an open oxygen and urine loop, and a closure of the wash and condensate loop. Similar assemblies and components of these EC/LSS subsystems will be used to sustain the experiment animals. Table 2 reflects the functions and equipment approaches for the Modular Space Station.

The six-man EC/LSS for the Modular Space Station is made up of two 3-man EC/LSS's interconnected. A listing of the assemblies for one of the three-man EC/LSS's and the respective weights and volumes, excluding thermal control, is shown in Table 3. Figure 2 is a simplified schematic of the overall integrated EC/LSS of the Space Station and shows major interfaces among the assemblies. Atmospheric stores (oxygen and nitrogen) and water will be piped to the experiment module from the main supply of either the Shuttle or Modular Space Station. Atmospheric pressure is maintained through a two-gas pressure control assembly. The Sabatier/methane dump and wick-fed electrolysis assemblies were the primary candidates for oxygen recovery. Carbon dioxide is controlled by a molecular sieve, and various contaminants make use of a nonregenerable/catalytic oxidation approach. Condensing heat exchangers control humidity, and condensate and wash water are reclaimed

TABLE 2. MODULAR SPACE STATION EC/LSS FUNCTIONS AND EQUIPMENT APPROACHES

Function	Approaches	Selected Candidate	Selected Approach
Oxygen Storage	Gaseous Tanks (Skylab A) Cryogenic Tanks	Cryogenic Tanks (Supercritical)	AAP Type
Nitrogen Storage	Cryogenic Tanks Gaseous Tanks (Skylab A)	Cryogenic Tanks (Supercritical)	AAP Type
Pressure Control	Two-Gas	101 353 N/m^2 (14.7 psia) N_2 Diluent	Skylab A
Airlock Repressurization	Gas Replacement	Gas Replacement	Skylab A
CO_2 Removal	Molecular Sieve	Molecular Sieve	
CO_2 Conversion (if ever used)	Sabatier — Bosch	Sabatier	Resize MDAC Simulator
O_2 Generation (if ever used)	Electrolysis	Wick Feed	
Trace Contaminant	Nonregenerable Charcoal/Catalytic Oxidation Regenerable Charcoal/ Catalytic Oxidation	Nonregenerable Charcoal/Catalytic Oxidation	Resize MDAC Simulator
Trace Contaminant Monitoring	Hybrid Gas Chromato- graph/Mass Spectrometer		Resize MDAC Simulator
Atmosphere Temperature Control	Air/Fluid H_x	Air/Fluid H_x	
Humidity Control	Air/Fluid H_x	Air/Fluid H_x	Resize MDAC Simulator
Ventilation	Fans, Ducts, Diffusers	Fans, Ducts, Diffusers	
Thermal Control Internal Loop External Loop	Active Water R-21 (Freon)	Active Same Same	Resize MOL Modify and Resize MOL
Urine H_2O Recovery (if ever used)	Closed Air Evaporation Vapor Compression	Closed Air Evapora- tion	
Wash H_2O Recovery	Multifiltration Reverse Osmosis	Multifiltration	Resize and Modify MDAC Simulator
Condensate H_2O Recovery	Multifiltration Reverse Osmosis	Multifiltration	
Potable H_2O Storage	Heated Tanks	Same	Skylab A
Urine Collection	Integrated and Automatic Air Entrainment	Same	Skylab A
Fecal Collection and Processing	Integrated Vacuum Drying Bagging/Dehydration	Integrated Vacuum Drying	Skylab A
EVA/IVA	Umbilical	Umbilical	Skylab A
Emergency O_2 Assemblies	Chlorate Candles/PLSS	Chlorate Candles/ PLSS	

TABLE 3. MODULAR SPACE STATION CORE MODULE ASSEMBLIES — THREE-MAN EC/LSS (PARTIALLY-CLOSED H_2O/OPEN O_2)

Assembly	Major Component or Type	Mass, kg	Weight,[a] lb	Volume,[a] m^3 (ft^3)
CO_2 Removal	Molecular Sieve	92.97 12.70	205 28 (s)[c]	0.340 (12) 0.085 (3.0)(s)[c]
O_2/N_2 Pressure Control	Standard	65.75 20.41	145 45 (s)	? 0.017 (0.6)(s)
Contaminant Control	Nonregenerable/Catalytic Oxidation	11.79 2.72	26 6 (s)	0.142 (5) 0.014 (0.5)(s)
Water Management	Plumbing, Valves	90.70 ?	200 ? (s)	? ? ? ?(s)
Condensate Loop	Multifiltration	6.80 0.91	15 2 (s)	0.028 (1) 0.006 (0.2)(s)
Wash Loop	Multifiltration	45.35 11.79	100 26 (s)	0.127 (4.5) 0.028 (1)(s)
Waste Management	Integrated Vacuum Drying	57.14 15.52	126 34 (s)	0.906 (32) 0.014 (0.5)(s)
Suit Loop	Plumbing, Supply Valves, etc.	32.20 2.72	71 6 (s)	0.425 (15) 0.006 (0.2)(s)
Contingency		45.35 6.35	100 14 (s)	0.227 (8) 0.028 (1)(s)
Total		448.05[b] 73.12	988[b] 161 (s)[c]	2.195 (77.5) 0.198(s)(7.0)(s)[c]

a. Conversion Factors: 0.0283 m^3/ft^3 and 2.205 lb/kg.
b. Does not include O_2, N_2, and H_2O tankage.
c. Indicates total spares weight or volume.

by a multifiltration assembly in the Modular Space Station (Option IV); however, reverse osmosis is also an excellent candidate for wash water recovery. Urine water recovery, which was not required on the Modular Space Station, could utilize air evaporation. Integrated vacuum drying is the waste management selection. A thermal control system consisting of fluid loop, radiators, heat exchangers, fans, etc., will be included on the Space Station.

The EC/LSS for the Space Shuttle will sustain the life of two men for 7 days. A summary weight and volume breakdown of all the EC/LSS assemblies (except thermal control), crew systems, and expendables is given in Table 4. Most of these assemblies, which are used with minimum modifications, are existing state-of-the-art life support hardware designed for the

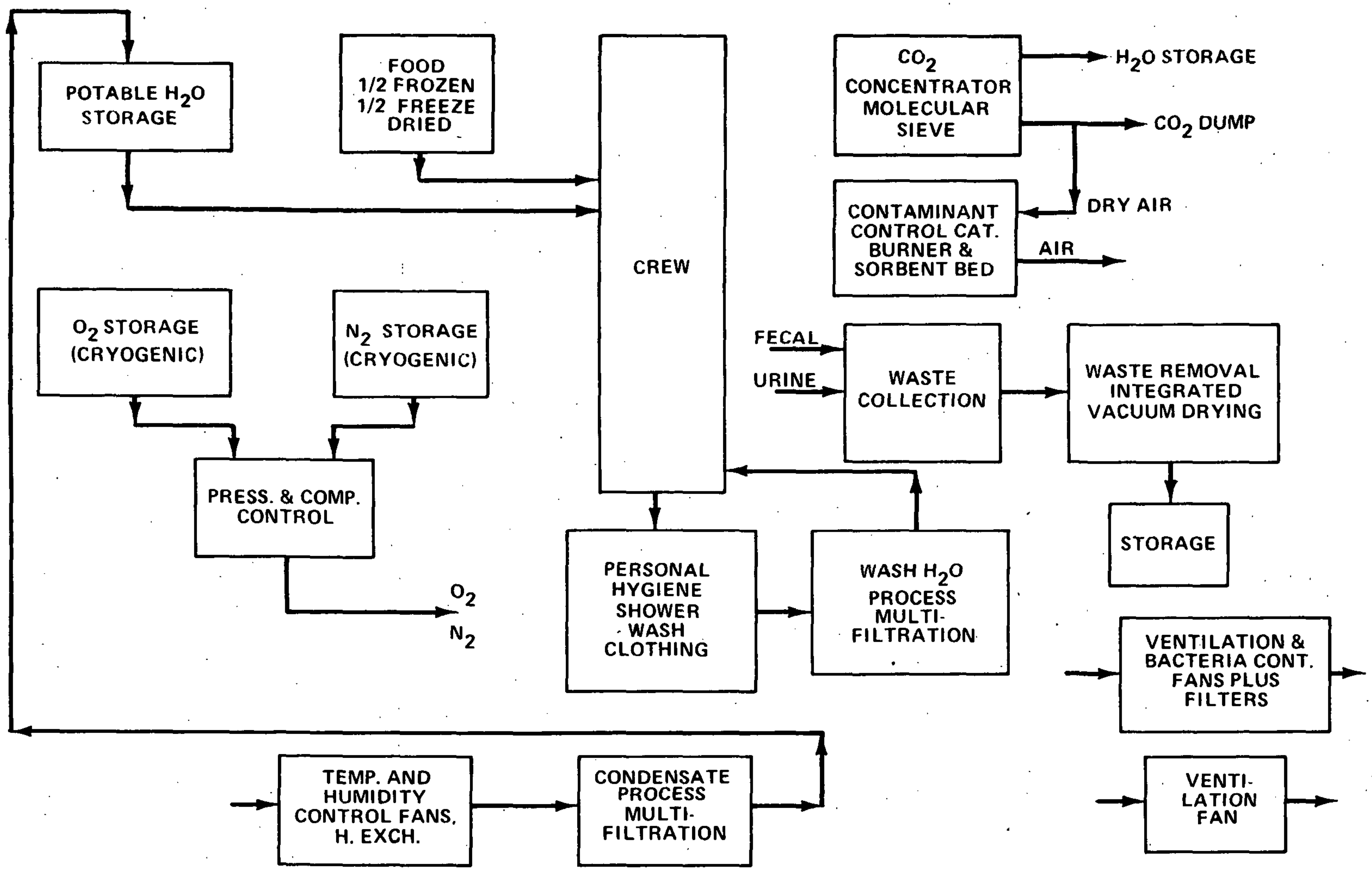

Figure 2. Modular Space Station EC/LSS schematic.

TABLE 4. SPACE SHUTTLE EC/LSS MASSES (WEIGHTS) AND VOLUMES (TWO-MEN; 7 DAYS)

Item	Mass, kg	Weight,[a] lb	Approximate Volume,[a] m^3 (ft^3)
Oxygen (includes initial fill)	38.55	85	0.142 (5)
Nitrogen (includes initial fill)	79.82	176	0.255 (9)
Atmospheric Supply and Pressurization	67.57	149	0.170 (6)
Atmospheric Purification and Control	69.39	153	0.453 (16)
Water Management	21.77	48	0.113 (4)
Waste Management	85.26	188	0.170 (6)
Crew Systems	38.55	85	0.085 (3)
Water (5.90 kg/man-day + 1-day reserve)	94.33	208	0.085 (3)
Food (plus 1-day reserve)	14.97	33	0.057 (2)
Four men	339.23	748	3.400 (120 ft^3) seated
Four seats	94.33	208	4.700 (166 ft^3) standing
Total	943.77	2 081	6.230 (220) (maximum)

a. Conversion factors: 0.0283 m^3/ft^3 and 2.205 lb/kg.

Apollo, Gemini, and LEM spacecraft. Figure 3 illustrates the Shuttle crew compartment EC/LSS.

SECTION III. ANIMAL ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEMS (REQUIREMENTS, GUIDELINES, ASSEMBLIES)

Laboratory animals most commonly utilized for research are lagomorphs (rabbits, hares, etc.) and rodents (guinea pigs, mice, rats, etc.).

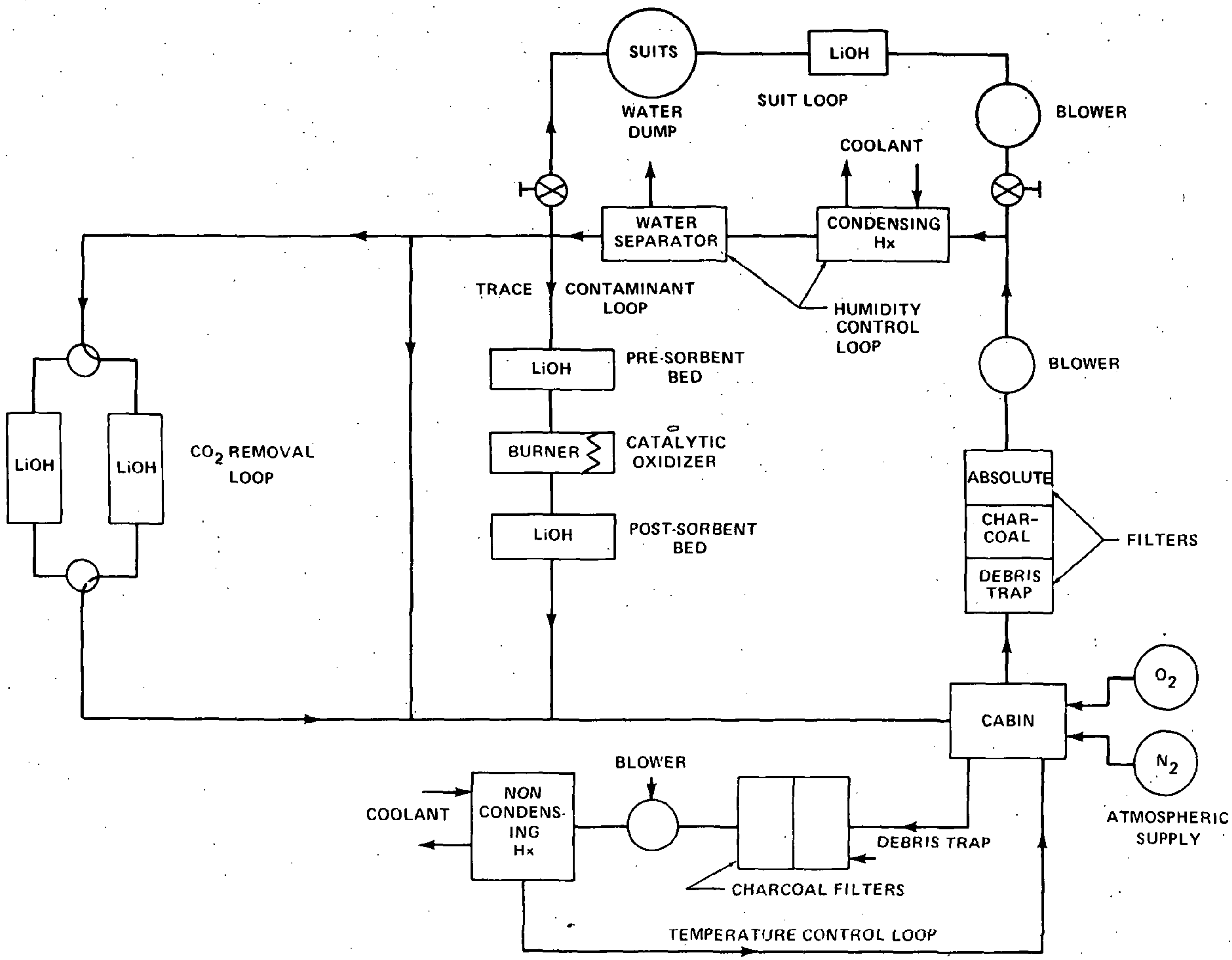

Figure 3. Space Shuttle crew compartment EC/LSS.

Rodents can be used to study diverse problems in genetics, metabolism, and nutrition. A comparatively large amount of data exists concerning rodents.

Primates that have been employed include various species of monkeys (primarily rhesus) and chimpanzees. Baseline data concerning these animals have been provided mostly by recently established primate colonies and experimental centers.

Dogs, cats, and ferrets are the most commonly employed carnivora. Cats are utilized to study the physiology of vision, hearing, vestibular, and nervous responses. Dogs are used to study renal, cardiovascular, and respiratory physiology.

One of the most significant developments in recent years is the appearance of several breeds of miniature swine. Basic data have been accumulated on more than three strains of miniature swine. Miniature swine, as well as dogs, cats, and primates, present a special problem in waste disposal. Research is required to develop, for animals of this type, a waste disposal assembly that will function in space, yet will not restrain the animal's movement. Several characteristics of the animals mentioned above are presented in Table 5.

The animals and plants identified are not necessarily the ones that ultimately will be used; however, they are examples of the types that will be used for research activities. Table 6 lists the plants and animals taken from Reference 2 that can be used in research activities.

Metabolic data on some of these animals of varying sizes were found in References 2 through 6 and are given in Table 7. Oxygen consumption, carbon dioxide removal, food weight, and water balance data are included in the data as well as design values for an astronaut. Metabolic values on certain animals could not be found and estimates had to be made. Water balance data were generally given per unit of body weight. The total water intake consisted of all ingested water plus water of oxidation, which is balanced by the urine, respiration, and perspiration water output. The perspiration and respiration water was assumed to be the difference between the total water output and urine water.

The experiment module for the minimum and maximum animal payloads must contain all the assemblies normally found in a semiclosed ecological EC/LSS. The animals eat food, drink water, consume oxygen, and generate CO_2, urine, feces, water vapor, heat, and trace contaminants just

TABLE 5. ANIMAL SUBJECT CHARACTERISTICS [3]

Species	Housing Volume, 10^{-2} m^3 (ft^3)	Rectal Temperature, °K (°F)	Heart Rate (per minute)	Respiration Rate (per minute)	Oestrus Cycle (days)	Mating Age (days)	Room Temperature, °K (°F)	Humidity (%)	Life Span (years)
Mouse	0.85 (0.3)	310.6 (99.3)	600	163	4-5	42-56	293.2-295.4 (68-72)	50-60	2
Rat	1.13 (0.4)	310.7 (99.5)	300	210	4-5	90-110	291.5-294.3 (65-70)	45-55	3
Dog	56.64 (20.0)	311.7 (101.4)	95	15	5-14	540	295.4 (72)	45-60	14
Cat	16.99 (6.0)	311.8 (101.6)	130	24	15-28	300	295.4 (72)	40-45	13
Primate	28.32 (10.0)	311.6 (101.1)	100	19	28	547-910	293.2-295.4 (68-72)	40-50	15
Swine	99.12 (35.0)	310.8 (99.8)	80-127	20	18-24	150-240	291.5-294.3 (65-70)	40-50	15

TABLE 6. PROPOSED EXPERIMENT PLANT AND ANIMAL TYPES (VERTEBRATES, INVERTEBRATES, PLANTS, AND TISSUES AND CELLS)

Vertebrates	Invertebrates	
	Insects	Planaria
Rhesus Monkey	Army Worm	Flat Worm
Macaque Monkey	Vinegar Gnat	Liver Fluke
Chimpanzee	House Fly	
Rat (White)	(Americal) Cockroach	
Ground Squirrel	Spider	
Golden Syrian Hampster	Flower Beetle (Tribolium)	
Mouse (White)		
Box Turtle		
Chicken		
Pocket Mouse		
Marmot		
Japanese Quail		
Goldfish		
Miniature Swine		
Rabbit		
Ambystom (Salamander)		
Frog (Xenopus Laervis)		
Rana Pipiens (Leopard Spotted Frog)		
Dog		
Cat		

Plants	Cells and Tissues
Dwarf Marigold	Frog Eggs
Arabidopsis	Carrot Tissue
Garden Peas (English)	Chick Embryo Cultures
Vigna Sinensis (Common Bean)	Neurospora (Bread Mold)
Pteris Gametophytes (Fern)	Chicken or Japanese Quail Eggs
Wheat	Rat and Mouse Tissues
Pepper Plant	Human, Rat, and Mouse Tissues
Corn Seedlings	Turtle Tissue
Spiderwort (Tradescantia)	Bacteria (Various Types)
Green Flagellated Algae	

as man does. Some different assemblies will undoubtedly be utilized in place of the manned assemblies for the animal EC/LSS. The animal EC/LSS assemblies for thermal control, atmospheric supply and pressurization, CO_2 removal, and O_2 reclamation (if used) should be very similar to those for man. If the Space Station includes oxygen reclamation in the EC/LSS, an enlarged version could process both animal and crew CO_2, with resulting savings over

TABLE 7. EC/LSS REQUIREMENTS FOR SELECTED VERTEBRATES

Requirement / Animal	Body Weight		O_2 Consumption			CO_2 Output			Food Weight		Solids Output	
	kg	lb	kg/day	lb/day	Man/ Animal	kg/day	lb/day	Man/ Animal	kg/day	lb/day	kg/day	lb/day
Astronaut [1]	71.8	158.32	0.834	1.84	1.0	0.961	2.12	1.0	0.807	1.78	0.408	0.90
Chimpanzee (Adult)	38.0	84.0	0.653[a]	1.44[a]	1.28[a]	0.757	1.67	1.27	0.29	0.64	0.0723	0.159
Monkey (Macaque)	4.2	9.26	0.052	0.1144	16.08	0.118	0.26	8.15	0.12	0.26	0.0298	0.066
Rat (White)	0.35	0.77	0.018	0.0397	46.35	0.019	0.042	50.47	0.02	0.044	0.0022	0.0049
Quail (Japanese)	0.172	0.379	0.018[a]	0.0397[a]	46.35[a]	0.019[a]	0.042[a]	50.47[a]	0.02[a]	0.044[a]	0.0022[a]	0.0049[a]
Hamster (Golden)	0.10	0.22	0.018	0.0397	46.35	0.019	0.042	50.47	0.02	0.044	0.0022	0.0049
Squirrel (Ground)	0.10[a]	0.22[a]	0.018[a]	0.0397[a]	46.35[a]	0.19[a]	0.042[a]	50.47[a]	0.02[a]	0.044[a]	0.0022[a]	0.0049[a]
Mouse (White)	0.021	0.046	0.018	0.0397	46.35	0.018	0.0397	53.40	0.005	0.011	0.0022	0.0049
Mouse (Pocket)	0.021	0.046	0.018	0.0397	46.35	0.018	0.0397	53.40	0.005	0.011	0.0022	0.0049
Chicken	1.81[a]	4.0[a]	0.052[a]	0.1144[a]	16.08[a]	0.118[a]	0.26[a]	8.15	0.12[a]	0.26[a]	0.0298[a]	0.066
Marmot	1.0	2.205	0.0274	0.0605	30.41	0.0283	0.0624	33.97	0.02[a]	0.044[a]	0.0022[a]	0.0049[a]
Box Turtle (Hatchlings)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Gold Fish	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

a. Estimate

TABLE 7. (Concluded)

Requirement / Animal	WATER BALANCE DATA													
	Body Weight		Drink		Oxidation		Turnover		Urine		Perspiration and Respiration		Fecal	
	kg	lb	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day
Astronaut [1]	71.8	158.32	2.78	6.13	0.30	0.66	3.08	6.79	1.565	3.45	1.40	3.09	0.113	0.25
Chimpanzee (Adult)	38.0	83.8	1.50	3.308	0.11	0.243	1.61	3.55	0.789	1.74	0.821	1.81	?	?
Monkey (Macaque)	4.2	9.26	0.29	0.64	0.05	0.11	0.34	0.75	0.22	0.485	0.122	0.269	?	?
Rat (White)	0.35	0.77	0.0487	0.1074	0.0091	0.0201	0.0578	0.1274	0.0203	0.045	0.0375	0.0827	?	?
Quail (Japanese)	0.172	0.379	0.0487[a]	0.1074[a]	0.0091[a]	0.0201[a]	0.0578[a]	0.1274[a]	0.0203[a]	0.045[a]	0.0375[a]	0.0827[a]	?	?
Hamster (Golden)	0.10	0.22	0.0184	0.0406	0.0032[a]	0.0071	0.0216	0.0476	0.0086	0.019[a]	0.013[a]	0.0287[a]	?	?
Squirrel (Ground)	0.10[a]	0.22[a]	0.0184[a]	0.0406[a]	0.0032[a]	0.0071[a]	0.0216[a]	0.0476[a]	0.0086[a]	0.019[a]	0.013[a]	0.0287[a]	?	?
Mouse (White)	0.021	0.046	0.0021	0.0047	0.0021	0.0046	0.0042	0.0093	0.0009	0.002	0.0033	0.0073	?	?
Chicken	1.81[a]	4.0[a]	0.29[a]	0.65[a]	0.05[a]	0.11[a]	0.34[a]	0.76[a]	0.22[a]	0.49[a]	0.122[a]	0.27[a]	?	?
Marmot	1.0	2.205	0.249	0.549	0.038	0.084[a]	0.287	0.633[a]	0.163	0.359[a]	0.123	0.271[a]	?	?
Box Turtle (Hatchlings)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	?	?
Gold Fish	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	?	?

two separate assemblies. The animal assemblies that will most probably be different are those for waste management, contaminant control, and water reclamation.

It was decided to select the assemblies and components necessary for the minimum payload (30-day Shuttle module) from the Shuttle crew compartment EC/LSS. It is a two-man EC/LSS with a growth and contingency factor of about 50 percent for the animals. Components and assemblies for the maximum payloads would be selected from those described in Section II for the Option IV Modular Space Station Study. A schematic (Fig. 4) is included to show the maximum payload flow diagram and the interfaces among the assemblies. Some of the basic EC/LSS criteria and requirements established for man, white rats, monkeys, and chimpanzees are listed in Table 8.

To obtain an estimate of the size of the EC/LSS required for the minimum and maximum experiment payloads previously stated, an equivalent system for man was appraised. Initial estimates of the experiment loads indicate an approximation of a one-man EC/LSS for the minimum payload, and a seven- and nine-man EC/LSS for the maximum payloads (laboratory and centrifuge). These capacities were based on the animals per man ratio of oxygen consumption and carbon dioxide output shown in Table 7.

Weights for the Shuttle module and centrifuge EC/LSS assemblies are given in Tables 9 and 10. These assemblies weigh 136 kg (300 lb), and 729 kg (1607 lb), respectively. The total weight of these assemblies, which include oxygen, nitrogen, food, and water, are 354 kg (781 lb) and 6309 kg (13 910 lb) and are detailed in Tables 11 and 12.

SECTION IV. ANIMAL FACILITY INSTALLATION

The EC/LSS equipment for the primary experiments is housed in the main experiment compartment on board a Space Station. The intended experiments for the Modular Space Station study are located in the compartments shown in Sections A-A, B-B, and C-C of Figure 1. The experiments should be housed where the crew can conveniently service the equipment.

The main experiment compartment for a Space Station might take on the appearance shown in Figure 5. This compartment, as described in Reference 4, has cage racks (Fig. 6) arranged concentrically close to the outside wall of the compartment designed to house small animals. The module pressure walls and the backs of the racks are accessible along the outer

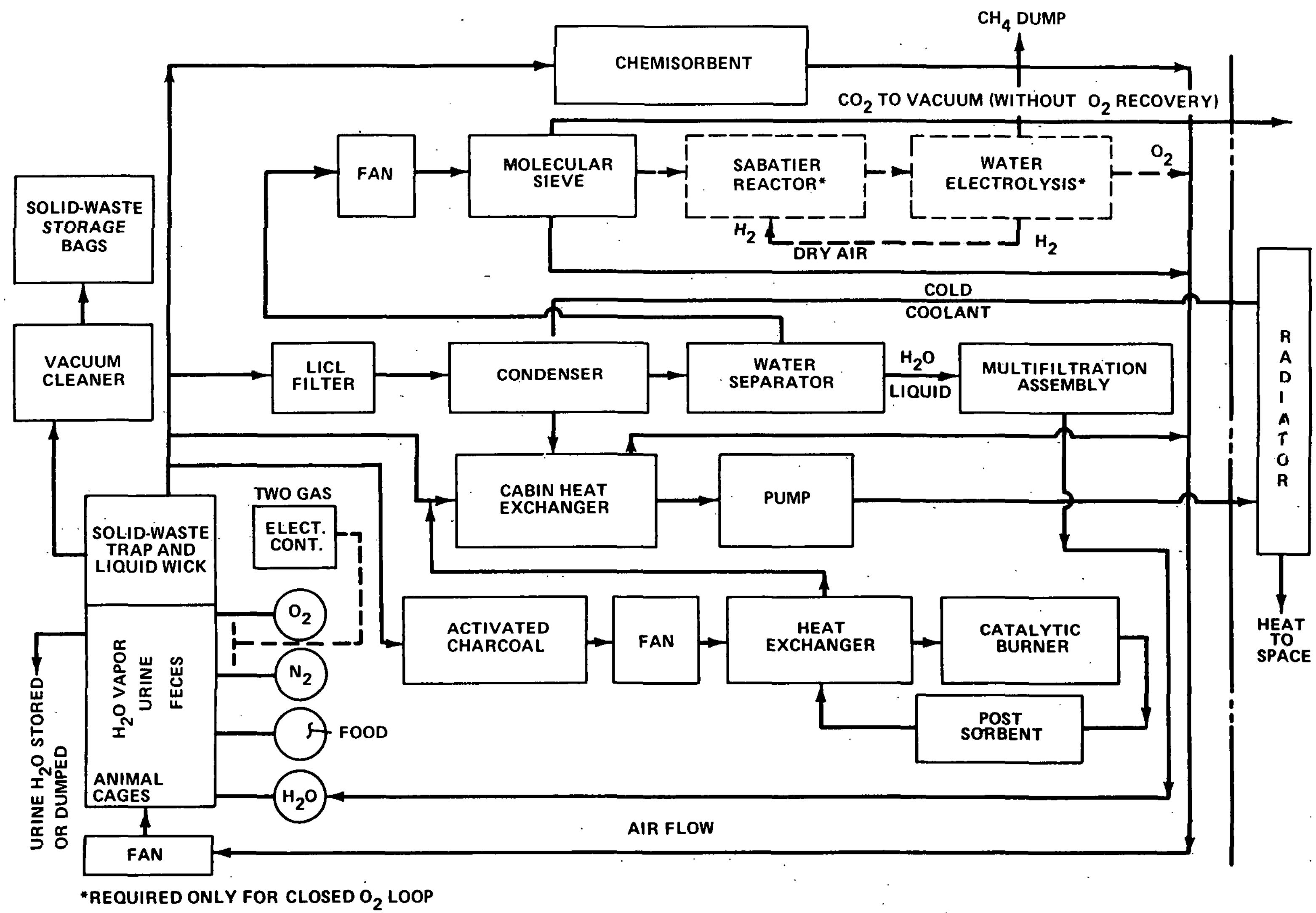

Figure 4. Animal EC/LSS diagram.

TABLE 8. MAN/ANIMAL EC/LSS CRITERIA AND REQUIREMENTS

	Units	
	SI[a]	CU[a]
A. Crew Data [in kg (or lb) /man-day unless otherwise designated]		
1. Metabolic Heat Generation — watts/man (Btu/man-day)	136.7	11 200
2. O_2 Consumption	0.834	1.84
3. CO_2 Produced	0.961	2.12
4. Water of Oxidation	0.30	0.66
5. Water Consumption Rates		
Drinking and Food Preparation	2.78	6.13
Washing and Personal Hygiene	11.97	26.04
Urinal Rinse	0.163	0.36
6. Water Production Rates		
Urine Water	1.565	3.45
Including Solids	1.64	3.62
Fecal Water	0.113	0.25
Including Solids	0.154	0.34
Water in Food Waste	0.063	0.14
Perspiration and Respiration	1.40	3.09
7. Water Reclamation Rates		
Wash Water	11.85	26.14
Urinal Rinse 95% Efficiency	0.155	0.34
Perspiration and Respiration 100% Efficiency	1.40	3.09
Urine 95% Efficiency	1.487	3.278
8. Freeze-Dried Food	0.717	1.58
Including Packaging	0.807	1.78
9. Frozen Food	1.36	3.00
Including Packaging	1.50	3.30
B. White Rat Data [in kg (or lb) /rat-day unless otherwise designated]		
1. Number of Rats	32 to	352
2. Metabolic Heat Generation—watts/rat (Btu/rat-day)	2.64	217
3. O_2 Consumption	0.018	0.0397
4. CO_2 Produced	0.019	0.042
5. Water of Oxidation	0.0091	0.0201
6. Drinking Water	0.0487	0.1074
7. Urine Water	0.0203	0.045
8. Perspiration and Respiration	0.0375	0.0827
9. Food	0.02	0.044
C. Macaque Monkey Data [in kg (or lb) /monkey-day unless otherwise designated]		
1. Number of Monkeys	2 to	4
2. Metabolic Heat Generation—watts/monkey (Btu/monkey-day)	16.59	1 360
3. O_2 Consumption	0.052	0.1147
4. CO_2 Produced	0.118	0.260

TABLE 8. (Concluded)

	UNITS	
	SI[a]	CU[a]
C. Macaque Monkey Data (Continued)		
5. Water of Oxidation	0.05	0.110
6. Drinking Water	0.29	0.640
7. Urine Water	0.22	0.485
8. Perspiration and Respiration	0.122	0.269
9. Food	0.12	0.265
D. Chimpanzee (Adult) Data [in kg (or lb) /chimp-day unless otherwise designated]		
1. Number of Chimpanzees	1 to	2
2. Metabolic Heat Generation (watts/chimp) (lb / chimp-day)	87.11	7 140
3. O_2 Consumption	0.653	1.44
4. CO_2 Produced	0.757	1.670
5. Water of Oxidation	0.11	0.243
6. Drinking Water	1.61	3.55
7. Urine Water	0.789	1.74
8. Perspiration and Respiration	0.821	1.81
9. Food	0.29	0.64
E. Baseline Mission Data		
1. Resupply Interval (days)	30	30
2. Onboard Reserves, Expendables (days)	30	30
F. Experiment Module Data		
1. Total Atmospheric Pressure — newtons /m^2 (psia)	101 353	14.70
2. Atmospheric Mixture — by volume	21 percent O_2 79 percent N_2	
3. O_2 Partial Pressure — newtons/m^2 (psia)	21 305	3.09
4. N_2 Partial Pressure — newtons/m^2 (psia)	80 048	11.61
5. CO_2 Partial Pressure, Nominal Maximum — newtons/m^2 (psia)	≤ 1014	0.147
	≤ 7.6 mm Hg - 1.00%	
6. CO_2 Emergency, Maximum — newtons/m^2 (psia)	≤ 2000	0.290
	≤ 15 mm Hg - 1.97%	
7. Cabin Temperature °K, (°F)	294.3 ± 2.78	70 ± 5
8. Relative Humidity (%)	55 ± 10	Same
9. Experiment Module Volume — m^3 (ft^3), 14 ft diameter by 58 ft	36.11	1275
10. Leakage (kg/day/module)	0.454	1.00
11. Repressurizations (open loop)	One	One

a. See Reference 9. U.S. customary units (CU) and International System of metric units (SI).

TABLE 9. ANIMAL EC/LSS DRY ASSEMBLY MASSES
(TWO-MAN EQUIVALENT, OPEN LOOP)

Assembly	Major Component or Type	Mass, kg	Weight,[b] lb
Atmospheric Supply and Pressurization	Plumbing, Valves, etc.[a]	73.9	163
Atmospheric Purification	LiOH, Filters, Sorbent Beds, etc.	18.1	40
Water Management	Plumbing, Valves, Tanks, etc.	16	35
Waste Management	Modified Tug	21.3	47.0
Contingency		6.7	15.0
Total		136.0	300

a. Does not include O_2 and N_2 tankage.
b. Conversion factor: 2.205 lb/kg.

passageway. Other EC/LSS equipment and ducts are arranged concentrically under the racks.

Common housing for various numbers of small vertebrates, such as rats, are provided in the cage racks. Other provisions are power, instrumentation, structural support, contaminant control, and interface connections for the EC/LSS. The animals are housed in individual cages within the cage racks.

Rats are the primary animals used for experimentation. A standard laboratory rat cage is approximately 17.78 cm by 17.78 cm by 25.4 cm (7 in. by 7 in. by 10 in.) and is fabricated from coarse-wire screen. This allows air circulation and the feces and urine to drop through the bottom of the cage. Water for a standard rat cage is provided through a capillary tube, and it is logical that water can be provided similarly in a zero-g cage.

SECTION V. ANIMAL ATMOSPHERIC SUPPLY AND PRESSURIZATION ASSEMBLY

The atmospheric supply and pressurization assembly for the animals must provide metabolic oxygen to the animals, maintain suitable partial

TABLE 10. ANIMAL EC/LSS DRY ASSEMBLY MASSES (NINE-MAN EQUIVALENT, FULLY CLOSED LOOP)[a]

Assembly	Major Component or Type	Mass, kg	Weight,[b] lb
O_2 Generation	Sabatier/Methane Dump	53.1	117
H_2O Electrolysis	Wick-fed	152.4	336
CO_2 Removal	Molecular Sieve	278.9	615
Contaminant Control	Nonregenerable Charcoal	35.4	78
Urine Recovery	Air Evaporation	117.9	260
Condensate Recovery	Multifiltration	20.4	45
Waste Management	Integrated Vacuum Drying	35.8	79
Contingency		34.9	77
Total		728.8	1607

a. Does not include O_2, N_2, and H_2O tankage.
b. Conversion factor: 2.205 lb/kg.

TABLE 11. TOTAL EC/LS SUBSYSTEM MASS SUMMARY (TWO-MAN EQUIVALENT, OPEN LOOP)

Components	Mass, kg	Weight,[a] lb
Two-Man EC/LSS	136	300
O_2 plus Tankage	0	0[b]
N_2 plus Tankage	0	0[b]
H_2O plus Tankage	166	366
Food plus Packaging	52	115
Total	354	781

a. Conversion factor: 2.205 lb/kg.
b. 71 kg (157 lb) O_2 and 110 kg (243 lb) N_2 contained in Shuttle cryogenic tanks.

TABLE 12. TOTAL EC/LS SUBSYSTEM MASS SUMMARY (NINE-MAN EQUIVALENT, FULLY CLOSED LOOP)

Components	Mass, kg	Weight,[a] lb
Nine-man EC/LSS (Centrifuge)	729	1607
O_2 plus Tankage	1279	2820
N_2 plus Tankage	450	992
H_2O plus Tankage	2942	6487
Food plus Packaging	909	2004
Total	6309	13 910

a. Conversion factor: 2.205 lb/kg.

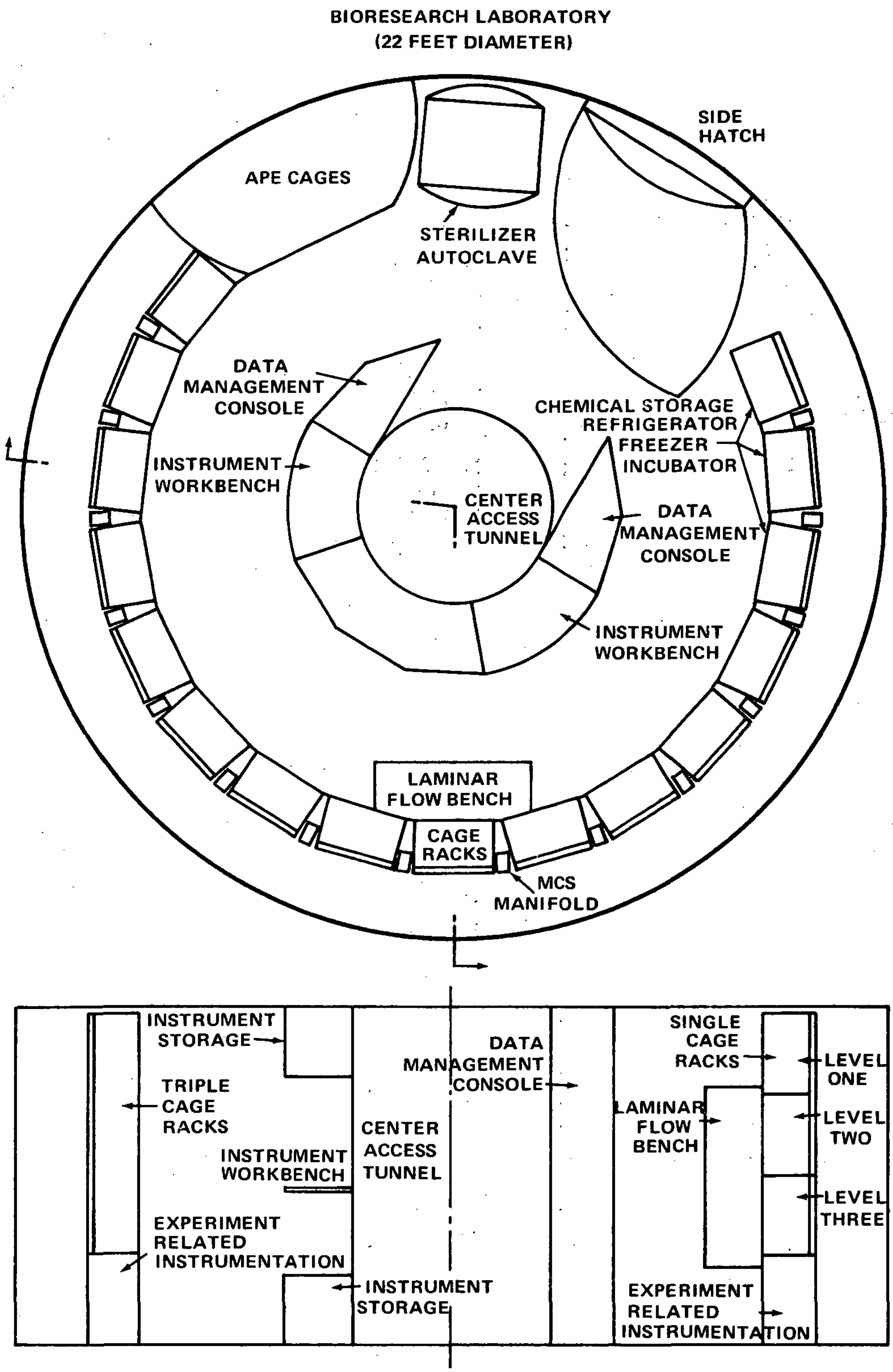

Figure 5. Main laboratory compartment.

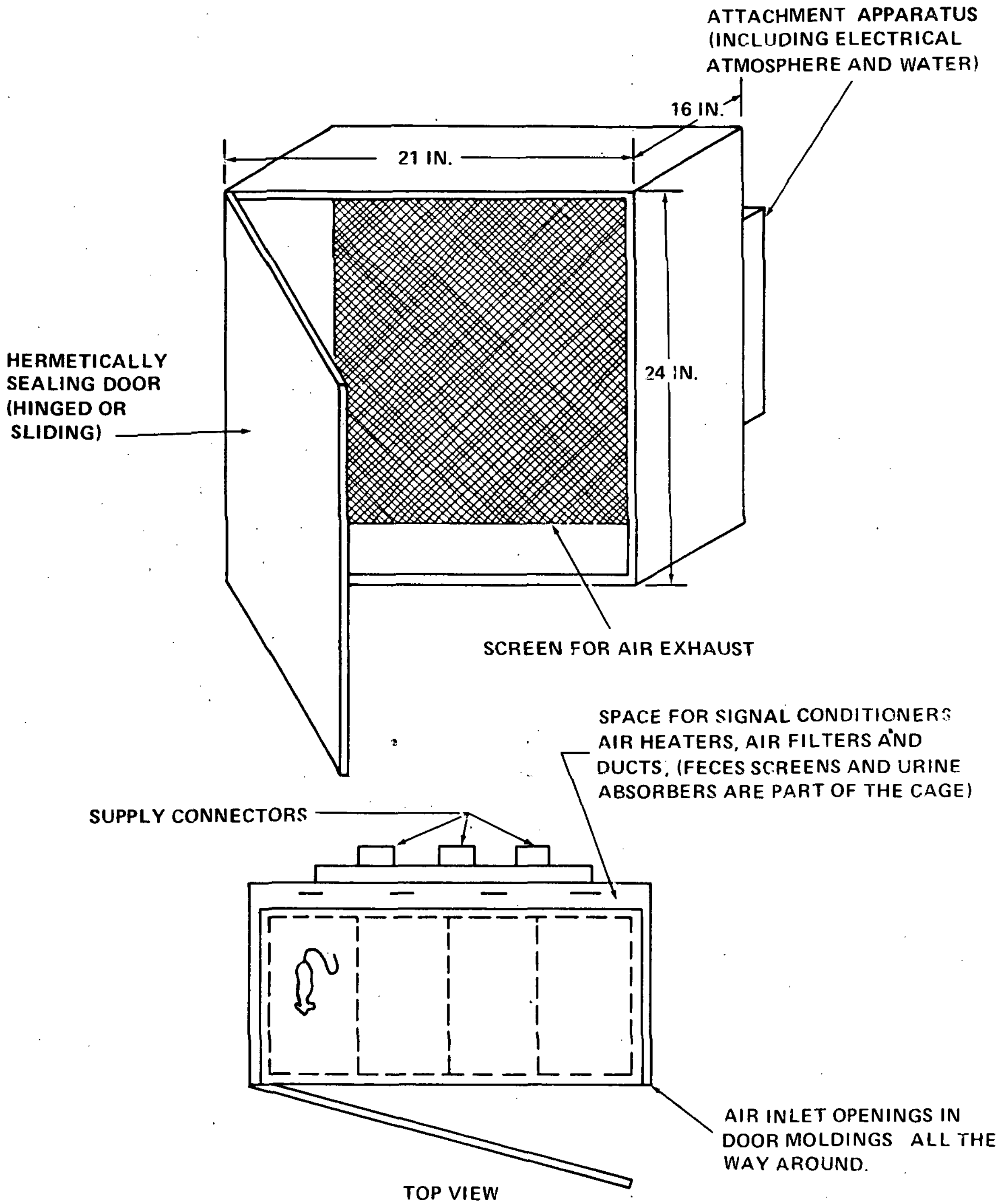

Figure 6. Cage rack.

pressures in the two-gas atmosphere, and control the carbon dioxide partial pressure at a nontoxic level. The atmospheric mixture currently planned for the animal experiment module contains approximately 21 percent oxygen and 79 percent nitrogen (except for traces of carbon dioxide and moisture). The atmosphere will be maintained at a total pressure of 101 353 newtons/m^2 (14.7 psia), which includes a partial pressure of 21 305 newtons/m^2 (3.09 psia) for the oxygen and 80 048 newtons/m^2 (11.61 psia) for the nitrogen.

Since the atmospheric pressure has been established as 101 353 newtons/m^2 (14.7 psia), the oxygen concentration must be between 16 and 35 percent, with the median tolerance being about 25 percent instead of the usual 21 percent for the comfortable survival of the animals. If the animal oxygen metabolism varies, there may be a more attractive nominal oxygen concentration. These values are extrapolated from human tolerances shown in Figure 7.[1] Human beings survive comfortably within these tolerances at 101 353 newtons/m^2 (14.7 psia); therefore, it can be expected that rats, monkeys, and chimpanzees could also. The high oxygen concentration is not tolerable simultaneously with atmospheric pressure; however, the high oxygen concentration is desirable if the atmospheric pressure falls.

The 30-day Shuttle animal colony (32 rats and 2 Macaque monkeys) consume approximately 21 kg of metabolic oxygen. The laboratory (256 rats, 2 Macaque monkeys, and 1 chimpanzee) and centrifuge (352 rats, 2 Macaque monkeys; and 1 chimpanzee) colonies will require much more metabolic oxygen due to the number of animals and the 90-day mission. This amounts to 483 kg (1065 lb) and 638 kg (1407 lb), respectively. Atmospheric leakage was assumed to be 1 lb per day for the biology experiment module. Additional oxygen and nitrogen, as reflected later in Tables 30, 31, and 32 of Section IX, are required for such purposes as pressurization, metabolic reserve, molecular sieve ullage, etc. A 30-day contingency is provided for emergencies such as food, water, nitrogen, and metabolic cryogen.

The oxygen and nitrogen consumables will possibly be stored in the Bendix Corporation AAP type tank (105.4 cm or 41.5-in. O.D.). Two AAP type cryogenic tanks are required to contain the oxygen (758 kg or 1671 lb) necessary for sustaining the laboratory colony. Likewise, two AAP tanks are needed to store the oxygen (975 kg or 2150 lb) for sustaining the centrifuge colony. Nitrogen (298 kg or 657 lb) for both the laboratory and centrifuge

---

1. Figures 7 and 8 were reproduced from NASA SP-3006, "Bioastronautics Data Book", Reference 7 of this document.

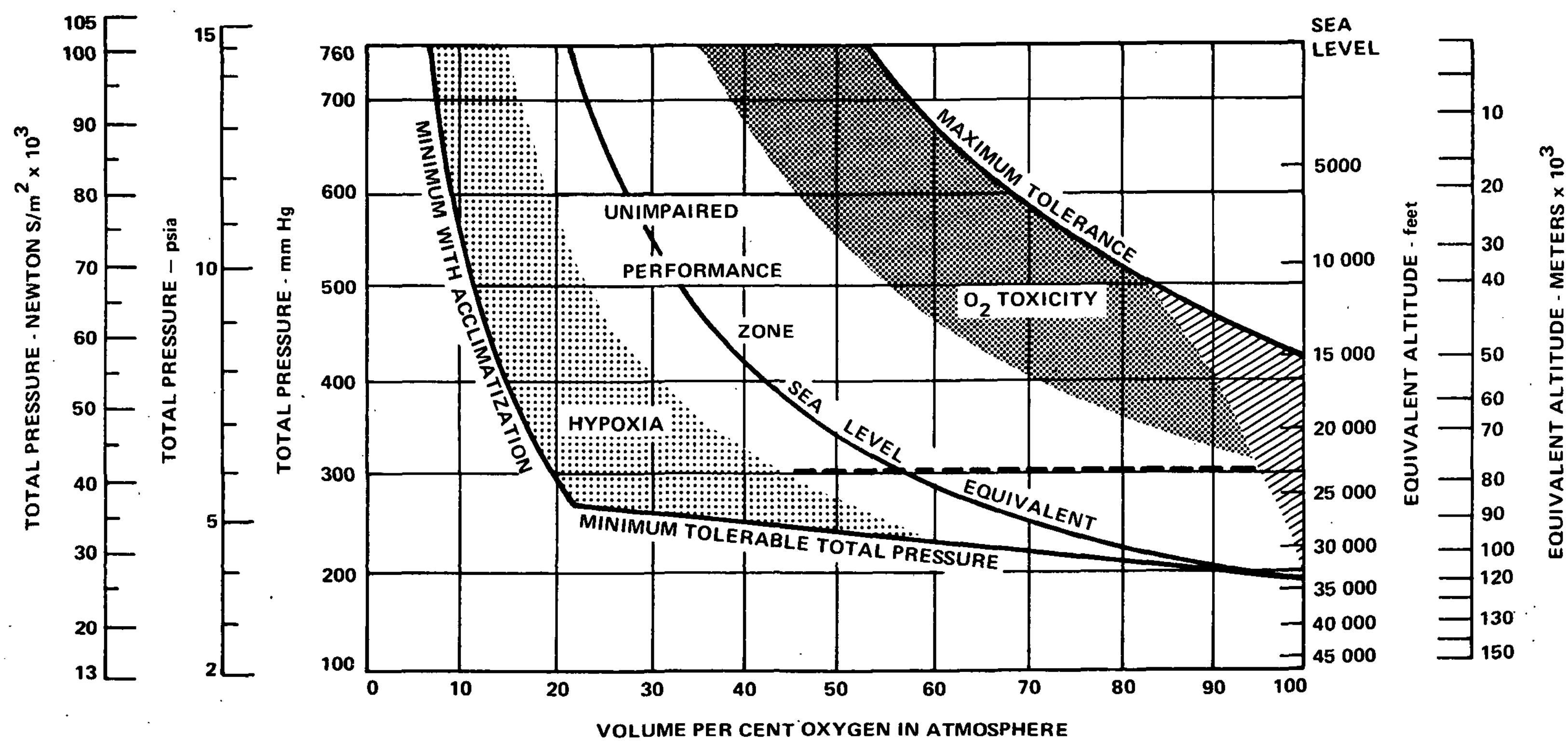

Figure 7. Physiological relations for percent of O_2 versus total pressure (confined aerospace vehicle atmosphere).

colonies will require one AAP tank each to satisfy leakage and pressurization purposes. The oxygen (71 kg or 157 lb) and nitrogen (110 kg or 243 lb) consumables needed for the 30-day Shuttle colony will be contained in the Space Station cryogenic tanks. Table 13 gives a mass breakdown of additional equipment that is required for the 30-day Shuttle Atmospheric Supply and Pressurization assembly.

Oxygen reclamation equipment may possibly be used for the laboratory and centrifuge colonies. This involves employing the Sabatier/methane dump reactor and "wick-fed" water electrolysis assemblies recommended for the Option IV Modular Space Station. A detailed weight breakdown of these assemblies for a three-man system is given in Tables 14 and 15. The capacities of the required manned assemblies are based on the animals per man ratio of oxygen consumption shown in Table 7. The total man equivalents for the Shuttle, laboratory, and centrifuge animal colonies are shown in Tables 16 and 17. These tables reflect assemblies for the animals which amount to a little less than a one-man assembly for the 30-day Shuttle module, approximately a seven-man assembly for the laboratory, and a nine-man assembly for the centrifuge. Since an open oxygen loop is being used on the 30-day Shuttle module, no oxygen recovery equipment is needed; however, three 3-man interconnected assemblies (Sabatier plus electrolysis) are required to sustain either the laboratory or the centrifuge colonies.

SECTION VI. ANIMAL ATMOSPHERIC PURIFICATION ASSEMBLY

The function of the atmospheric purification assembly is essentially the same as the manned assembly. The contaminants, carbon dioxide, and bacteria produced by the animals must be maintained within acceptable limits. The contaminant components must prevent cross-contamination between sets of animal cages. If a common contaminant removal loop is used for all the animals, removal of the contaminants must be 100 percent effective before the fresh air is routed back to the animals. A common loop is being assumed.

Animal life will liberate feces, urine, flatus, and carbon dioxide. Carbon dioxide and water are the principal contaminants released in the animal atmosphere; however, other contaminants such as ammonia from the urine, and methane and hydrogen sulfide from feces will appear. Establishing close tolerances for these contaminants seems difficult in view of the lack of information concerning the amounts generated by the animals. An adequate amount of activated charcoal can be provided in the atmospheric purifier to control these contaminants. Carbon dioxide is due to the animal metabolism of oxygen,

TABLE 13. ATMOSPHERIC SUPPLY AND PRESSURIZATION MASS

Component	No. Required	Mass, kg	Weight,[b] lb
O_2 Tankage[a]			
N_2 Tankage[a]			
O_2 and N_2 Plumbing		11.3	25
O_2 Heat Exchanger	1	2.27	5
N_2 Heat Exchanger	1	2.27	5
Controller, Total Pressure	1	1.22	2.7
Valve, Cabin Dump, and Relief	2	4.08	9
Regulator, Pressure O_2/N_2	2	2.27	5
Pressure Control Heat Exchanger	1	5.0	11
Delivery Selector Valve	1	0.91	2
Pressure Transducer	2	0.82	1.8
Valve, Shutoff	2	0.27	0.6
Chlorate Candles and Canisters	2	39.5	87
Contingency (5%)		4.0	8.9
Total		73.91	163

a. 71 kg (157 lb) O_2 and 110 kg (243 lb) N_2 contained in station cryogenic tanks. (See Table 33.)
b. Conversion factor: 2.205 lb/kg.

TABLE 14. OXYGEN RECOVERY ASSEMBLY (SABATIER) DETAILED MASS AND POWER BREAKDOWN (THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Sabatier/Methane Dump			
Sabatier Reactor	1	2.27	5.0
Pressure Transducer	3	0.68	1.5
CO_2 Orifice	1	0.022	0.05
Pressure Ratio Regulator	1	0.57	1.25
H_2 Orifice	1	0.022	0.05
Flow Transducer	2	0.91	2.0
CH_4 Orifice	1	0.022	0.05
Shutoff Valve	6	0.82	1.80
Cycle Accumulator	2	2.72	6.0
O_2 Warning Sensor	1	0.045	0.1
Signal Conditioner	1	0.23	0.5
Temperature Transducer	2	0.18	0.4
Signal Conditioner	2	0.27	0.6
Solenoid Valve	2	0.23	0.5
Timer, Electrical	1	0.091	0.2
Condenser/Water Separator	1	2.72	6.0
Temperature Control Valve	1	0.45	1.0
Temperature Controller	1	0.41	0.9
Installation Provisions		5.03	11.1
Total		17.69	39.0

a. Conversion factor: 2.205 lb/kg.

TABLE 15. WATER ELECTROLYSIS ASSEMBLY DETAILED MASS BREAKDOWN (THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Check Valve	2	0.27	0.6
Shutoff Valve	4	2.18	4.8
Electrolysis Module	1	21.77	48.0
Condenser/Separator	1	2.72	6.0
Hydrogen Regulator	1	0.54	1.2
Oxygen Regulator	1	0.54	1.2
Circulation Pump	1	0.68	1.5
Gas/Liquid/Solids Separator	1	2.72	6.0
Controller	1	0.82	1.8
Solenoid Shutoff Valve	1	0.68	1.5
Cold Plate	1	1.81	4.0
Instrumentation		4.54	10.0
Plumbing and Wiring		4.08	9.0
Insulation		1.36	3.0
Mounting		1.36	3.0
Contingency		4.72	10.4
Total		50.79	112.0

a. Conversion factor: 2.205 lb/kg.

TABLE 16. TYPICAL ANIMAL OXYGEN LOADING (LABORATORY AND CENTRIFUGE COLONIES)

Animal	Plant or Animal No. (Lab.)	Plant or Animal No. (Centrifuge)	Man/Animal	Total Man Equivalent (Lab.)	Total Man Equivalent (Centrifuge)
Chimpanzee (Adult)	1	1	1.28	0.781[a]	0.781[a]
Monkey (Macaque)	2	2	16.08	0.124	0.124
Rat (White)	256	352	46.35	5.523	7.594
Marigold (Plant)	144	144	Nil	Nil	Nil
Invertebrates	3	3	Nil	Nil	Nil
Cells and Tissues	4	4	Nil	Nil	Nil
Overall Man Equivalent				6.428	8.499

a. Estimate

TABLE 17. TYPICAL ANIMAL OXYGEN LOADING (30-DAY SHUTTLE MODULE COLONY)

Animal	Plant or Animal No. (Lab.)	Man/Animal	Total Man Equivalent, (Lab.)
Monkey (Macaque)	2	16.08	0.124
Rat (White)	32	46.35	0.69
Marigold (Plant)	16	Nil	Nil
Invertebrates	2	Nil	Nil
Cells and Tissues	2	Nil	Nil
Overall Man Equivalent			0.814

and water results from perspiration and respiration. Various contaminant components will have to contend with other contaminants (Table 18), such as those produced in the 90-day manned test performed in the MDAC Space Station simulator. These contaminants were reviewed and assigned contingency and abort levels by the National Academy of Science (NAS) and the National Research Council (NRC).

Carbon dioxide (CO_2) concentration for the animal atmosphere must be controlled to an acceptable level. Figure 8 [7] shows human tolerance for carbon dioxide, which can be used with the supposition that the animals have a similar tolerance. In Figure 8, A shows the short-term tolerance and B the long-term tolerance, which is more applicable for a 6-month experiment. For the long-term objective, a 0.5 percent maximum is indicated for carbon dioxide level, with, however, a rather large tolerance up to 2.5 percent with only minor discomfort. Carbon dioxide concentrators should be designed to maintain carbon dioxide concentrations at or below 0.5 percent for normal activity and metabolism by the animals. For higher rates of animal activity and metabolism, the carbon dioxide concentrations should not exceed 2.5 percent for the short durations of animal activity. The bar graph (B in Fig. 8) shows that for prolonged exposures of 40 days, concentrations of CO_2 in air of less than 0.5 percent (zone A) cause no biochemical or other effects; concentrations between 0.5 and 3.0 percent (zone B) cause adaptive biochemical changes, which may be considered a mild physiological strain; and concentrations above 3.0 percent (zone C) cause pathological changes in basic physiological functions.

The selected CO_2 concentrator should maintain the partial pressure of CO_2 at approximately 4 mm Hg (0.077 psia) and provide pure CO_2 for oxygen recovery processing, if required. The average CO_2 concentration during the 90-day MDAC test time was approximately 5 mm Hg (0.057 psia) rather than the intended 4 mm Hg (0.077 psia). The cabin atmosphere CO_2 concentration during the 90-day run is shown in Figure 9, which has the abnormal operation peaks numbered. Carbon dioxide removal can be accomplished for the 30-day module animal colony by a CO_2 absorber canister, where the CO_2 is removed by lithium hydroxide. More sophisticated equipment will have to be employed for the maximum payloads, such as a manned molecular sieve or solid amine assembly. The capacities of the required assemblies were based on the animals per man ratio of carbon dioxide production and are given in Table 7. The animal assembly requirements for the 30-day Shuttle module, laboratory, and centrifuge colonies for these assemblies are depicted in Tables 19 and 20. The tables establish that equivalent manned carbon dioxide assemblies are less than a one-man assembly for the 30-day Shuttle colony, approximately a seven-man assembly for the laboratory, and a nine-man assembly for the centrifuge.

TABLE 18. MAJOR ATMOSPHERIC CONTAMINANTS IN MDAC SPACE STATION SIMULATOR [8]

Contaminant	Accuracy	Normal Operations	Lower End of Contingency Operations	Abort Level
CO (ppm)	±2.0	12.0	100	200
CO_2 (mm Hg)	±0.4	4.0	8	a
Hydrocarbons (ppm)	±2.0	4.0	60	300
NH_3 (ppm)	±1.0	4.0	75	150
Aldehydes (ppm)	±0.005	1.0	15	25
SO_2 (ppm)	±0.25	0.5	7	12
H_2S (ppm)	±1.0	1.0	15	30
$(NO)_x$ (ppm NO_2)	±0.1	0.5	1.5	15
O_3 (ppm)	±0.001	0.03	0.15	1.5
Chlorine (ppm)	±0.04	0.1	0.7	1.5
Cyanides (ppm)	±1.0	1.0	3.0	15
Phosgene (ppm)	±0.2	0.07	0.15	1.5
Ethanol (ppm)	±0.2	2.5	300	1500
Toluene (ppm)	±0.2	0.5	30	300
2-Ethyl Butanol (ppm)	±0.2	1.0	20	60
N-Butanol	±0.2	1.0	15	150
2-Butanone	±0.2	2.0	30	300
Chloroform	±0.2	0.5	7	70
Dichloromethane	±0.2	2.5	40	700
Dioxane	±0.2	1.0	15	150
Ethylacetate	±0.2	4.0	60	600
2-Methylbutanone	±0.2	2.0	30	300
Trichloroethylene	±0.2	1.0	15	150
1, 1, 2-Trichloro; 1, 2, 2-Trifluoroethane and Related Congeners	±0.2	20	150	1500
Formaldehyde	--	0.05	0.15	3.0
Dichlorolacetylene	--	0	Detected	0.1
Vinylidene Chloride	--	2.0	10	25

a. Greater than 60 (3 minutes); 60 to 40 (10 minutes); 40 to 30 (30 minutes); 30 to 20 (60 minutes); 20 to 15 (48 hours).

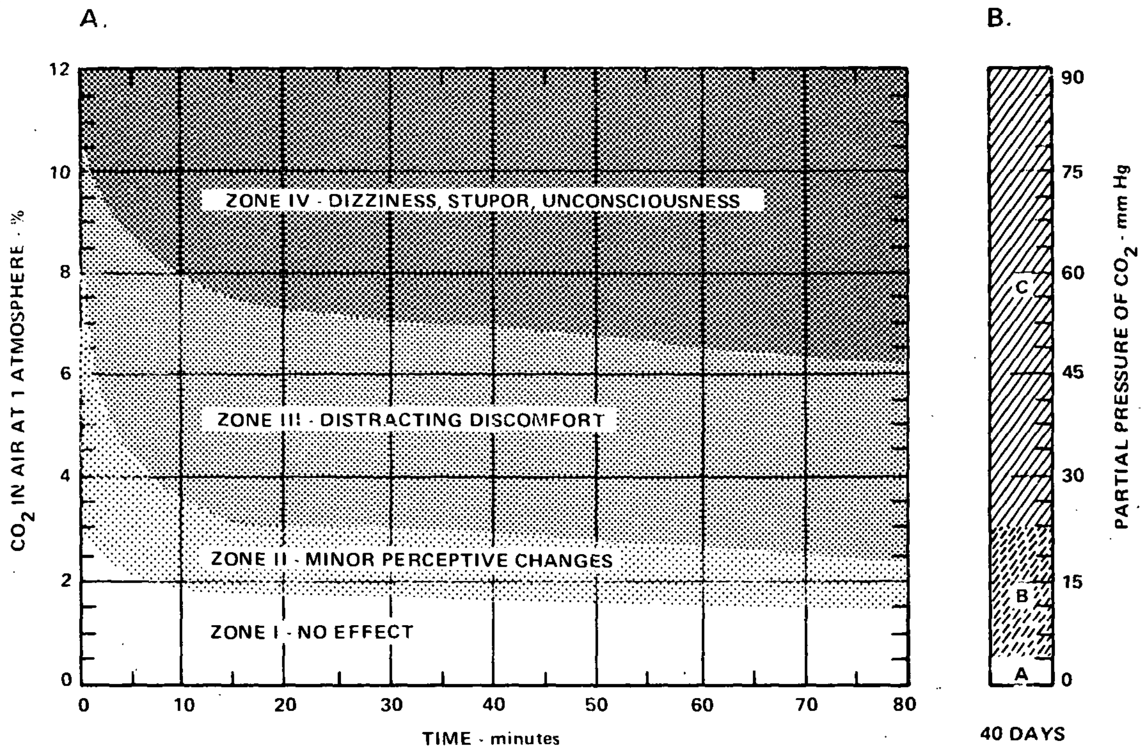

Figure 8. General manned symptoms to mixtures of CO_2 in air at 1 atmosphere.

The atmospheric purification assembly for the 30-day Shuttle module colony is illustrated in Figure 3. A cabin blower is employed to transfer the cabin gas through a debris trap, particulate filter, to remove both large and small particles and an activated charcoal filter, which removes the minute contaminants and odors. The gas then enters the unit heat exchanger for humidity control where the gas is cooled and the excess water is condensed, removed, and dumped overboard. Next the gas enters the CO_2 absorber canister where the CO_2 is removed by lithium hydroxide. The absorber elements are to operate in parallel inside the canister. This diverts half the flow into each element as the gas passes through the CO_2 canister. Other cabin atmosphere trace contaminants are passed through a pre-sorbent bed containing lithium hydroxide, through a catalytic oxidizer, where the flow is heated within a few degrees of the required catalyst operating temperature, and then through a post-absorbent bed containing lithium hydroxide for removing oxidation products. A detailed mass breakdown of the atmospheric purification components for the 30-day Shuttle module colony is shown in Table 21.

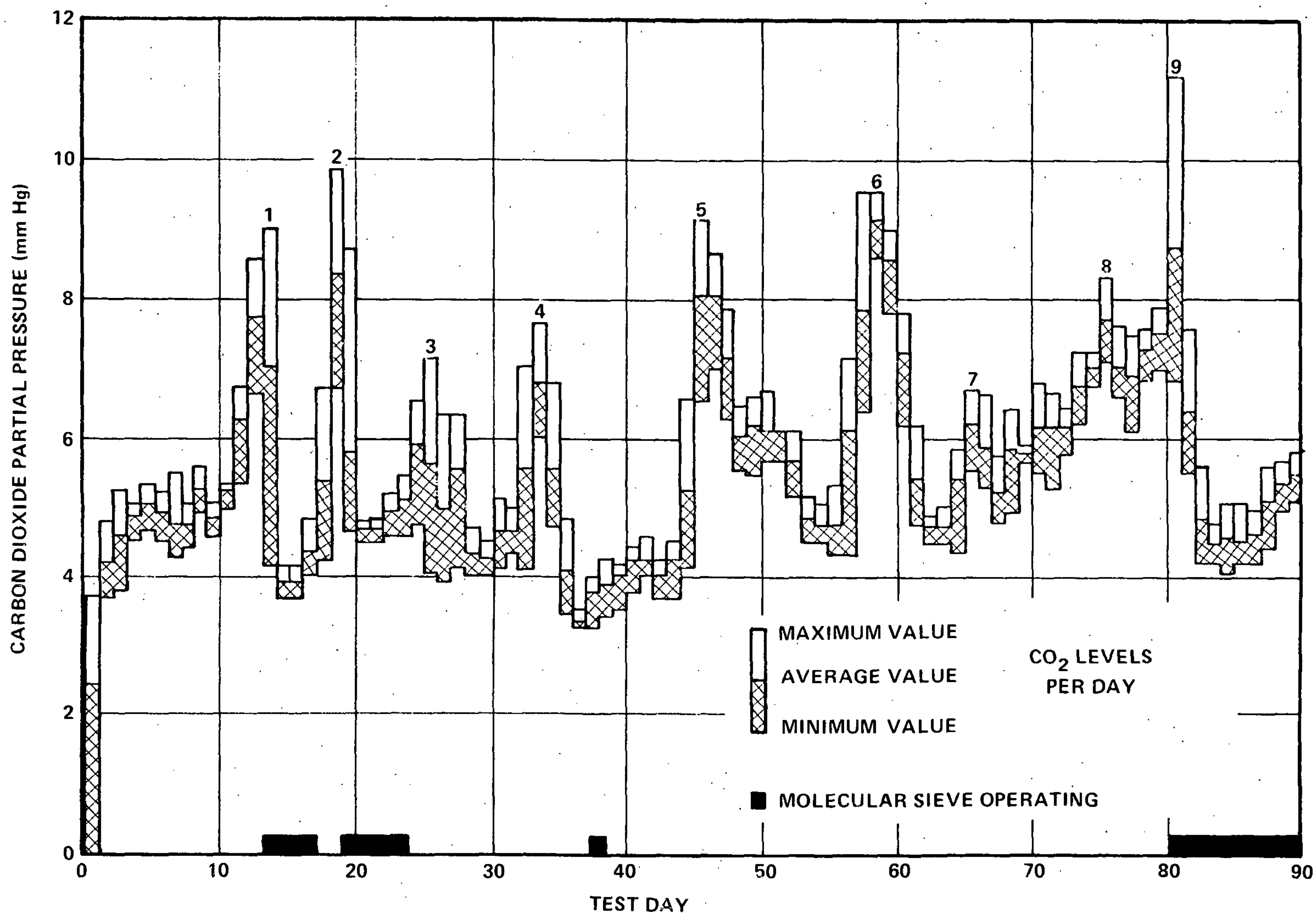

Figure 9. MDAC 90-day carbon dioxide partial pressure test.

TABLE 19. TYPICAL ANIMAL CARBON DIOXIDE LOADING (30-DAY SHUTTLE MODULE COLONY)

Animal	Plant or Animal No.	Man/Animal	Total Man Equivalent
Monkey (Macaque)	2	8.15	0.245
Rat (White)	32	50.47	0.63
Marigold (Plant)	16	Nil	Nil
Invertebrates	2	Nil	Nil
Cells and Tissues	2	Nil	Nil
Overall Man Equivalent			0.875

TABLE 20. TYPICAL ANIMAL CARBON DIOXIDE LOADING

Animal	Plant Or Animal No. (Lab.)	Plant Or Animal No. (Centrifuge)	Man/Animal	Total Man Equivalent (Lab.)	Total Man Equivalent (Centrifuge)
Chimpanzee (Adult)	1	1	1.27	0.787	0.787
Monkey (Macaque)	2	2	8.15	0.245	0.245
Rat (White)	256	352	50.47	5.072	6.974
Marigold (Plant)	144	144	Nil	Nil	Nil
Invertebrates	3	3	Nil	Nil	Nil
Cells and Tissues	4	4	Nil	Nil	Nil
Overall Man Equivalent				6.104	8.006

Atmospheric purification components for the laboratory and centrifuge animal colonies will be taken from the Option IV Modular Space Station candidates. A molecular sieve removes carbon dioxide and a nonregenerable/catalytic oxidation assembly controls contaminants. Another excellent candidate for carbon dioxide removal is the solid amine assembly. During the 90-day MDAC simulator test, the solid amine served as the baseline assembly, and the molecular sieve was the backup. These assemblies are shown in Figures 10 and 11.

TABLE 21. ATMOSPHERIC PURIFICATION ASSEMBLY MASS (TWO-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Debris Trap	1	0.37	0.82
Particulate Filter	1	0.62	1.36
Activated Charcoal Filter	1	0.82	1.81
Heat Exchanger	1	1.09	2.40
CO_2 Absorber Filter Assembly	2	1.65	3.63
CO_2 Absorber Canister	2	4.93	10.88
Fans	3	0.80	1.77
Catalytic Oxidizer	1	2.14	4.72
Pre-sorbent Bed	1	0.45	1.00
Post-sorbent Bed	1	0.41	0.91
Gauges and Valves		4.53	9.98
Contingency		0.29	0.64
Total		18.10	39.92

a. Conversion factor: 2.205 lb/kg.

During the 90-day test, the solid amine assembly required a significant amount of maintenance; however, this was not unexpected considering the state of development. The molecular sieve encountered only minor problems and proved to be satisfactory. The molecular sieve is the selected approach for carbon dioxide removal. A detailed mass breakdown of a three-man molecular sieve assembly is shown in Table 22. Three molecular sieve assemblies must be interconnected to obtain the nine-man capacity.

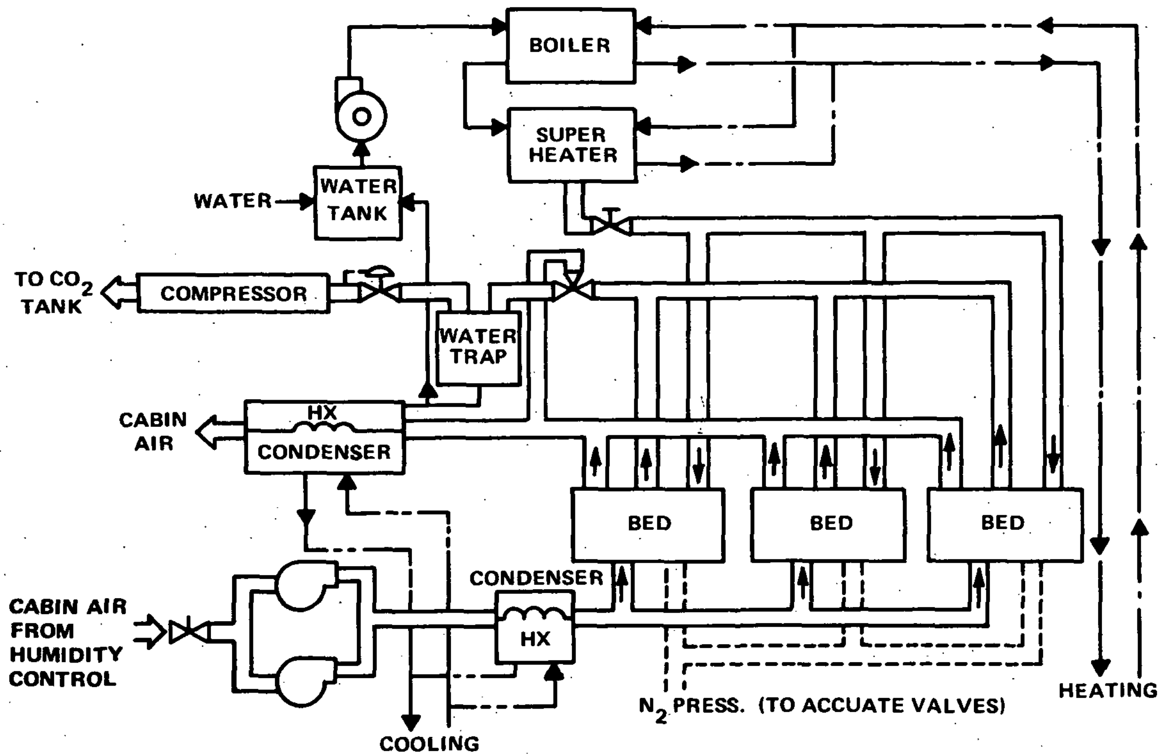

Figure 10. CO_2 concentrator — solid amine unit.

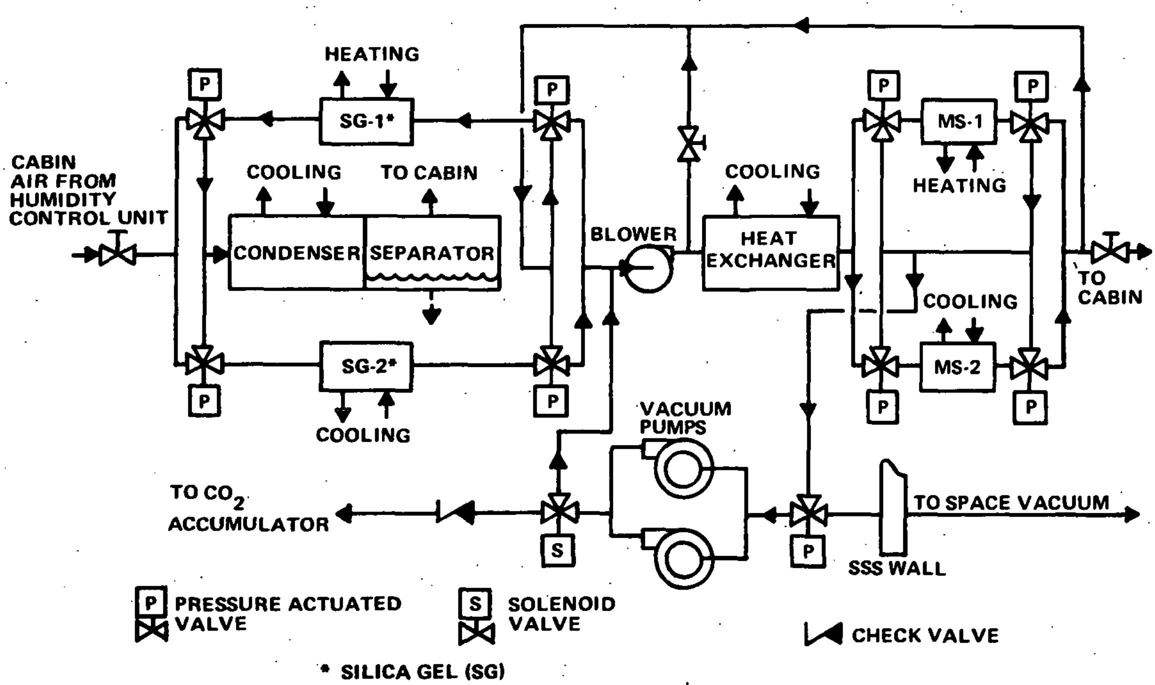

Figure 11. CO_2 concentrator — molecular sieve unit.

TABLE 22. MOLECULAR SIEVE ASSEMBLY
DETAILED MASS BREAKDOWN
(THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Fan	1	2.95	6.5
Heater	1	0.68	1.5
Silica Gel Canister	2	21.77	48.0
Molecular Sieve Canister	2	21.77	48.0
Regenerative H/X	1	9.07	20.0
Coolant Diverter Valves	6	4.08	9.0
Canister Diverter Valves	4	2.72	6.0
Startup Valve	1	0.68	1.5
Shutoff Valve	3	0.55	1.2
Vacuum Pump	1	9.98	22.0
CO_2 Cooler	1	0.68	1.5
CO_2 Accumulator	1	6.08	13.4
CO_2 Compressor	1	2.95	6.5
CO_2 Diverter Valve	1	0.68	1.5
Valve Sequence Controller	1	2.72	6.0
CO_2 Sensor	2	2.36	5.2
Heater/Controller	1	0.82	1.8
Humidity Sensor	2	0.23	0.5
Pressure Sensor	3	0.95	2.1
Speed Sensor	3	0.54	1.2
Temperature Sensor	6	0.54	1.2
Total		92.80	204.6

a. Conversion factor: 2.205 lb/kg.

The basic components of the molecular sieve unit are two silica gel beds in parallel, a heat exchanger, a circulation blower (Apollo suit compressor), two molecular sieve beds in parallel, a sequence timer, manifolds, and sequence control valves. A condenser and zero-g water separator are provided to remove water vapor from the silica gel beds desorption air stream.

Basic to the operation of the molecular sieve assembly is a sorbent material that has a high affinity for CO_2; an artificial zeolite (molecular sieve) is used. Two canisters function alternately in absorbing and desorbing modes. Since the sorbent has a preferential affinity for water vapor, an additional pair of desiccant canisters, usually containing silica gel, is used to absorb the moisture from the air stream before it enters the CO_2 removal beds.

The nonregenerable charcoal concept, which is the major contaminant control assembly for the laboratory and centrifuge colonies, is depicted in Figure 12. The major components of this concept are a charcoal bed with replaceable cartridges, a catalytic burner, and a post-sorbent bed containing lithium carbonate. The charcoal bed is intended to remove most of the general contaminants. The catalytic oxidizer rather than the charcoal is the main contaminant control device. It is intended to remove such gases as methane, hydrogen, and carbon monoxide. A catalyst such as 0.5 percent palladium or alumina operating at 700° F is recommended. The post-sorbent bed is designed to remove gases that may form in the oxidizer. Detailed weights of the assembly mass for a three-man capacity are listed in Table 23. Three such assemblies must be interconnected to provide the nine-man capacity needed.

SECTION VII. ANIMAL WATER MANAGEMENT/WATER RECLAMATION ASSEMBLY

Water management consists of storing or reclaiming the required amount of water to supply the 30-day Shuttle module, laboratory, or centrifuge animal colonies. The water must always be sterile and free of organic and inorganic toxic material. The amounts of water needed by the animals is approximately 2.529 kg (5.576 lb) per day for the 30-day Shuttle colony, 17.09 kg (37.68 lb) per day for the laboratory colony, and 22.64 kg (49.92 lb) per day for the centrifuge colony.

Approximately 76 kg (167.58 lb) of water are required every 30 days for the Shuttle module animal colony. The laboratory and centrifuge animal colonies will require 1538 kg (3391 lb) and 2038 (4494 lb), respectively, every 90 days. A water balance table for the 30-day Shuttle module colony is given in Table 24. Similar tables could be developed for the laboratory and centrifuge colonies.

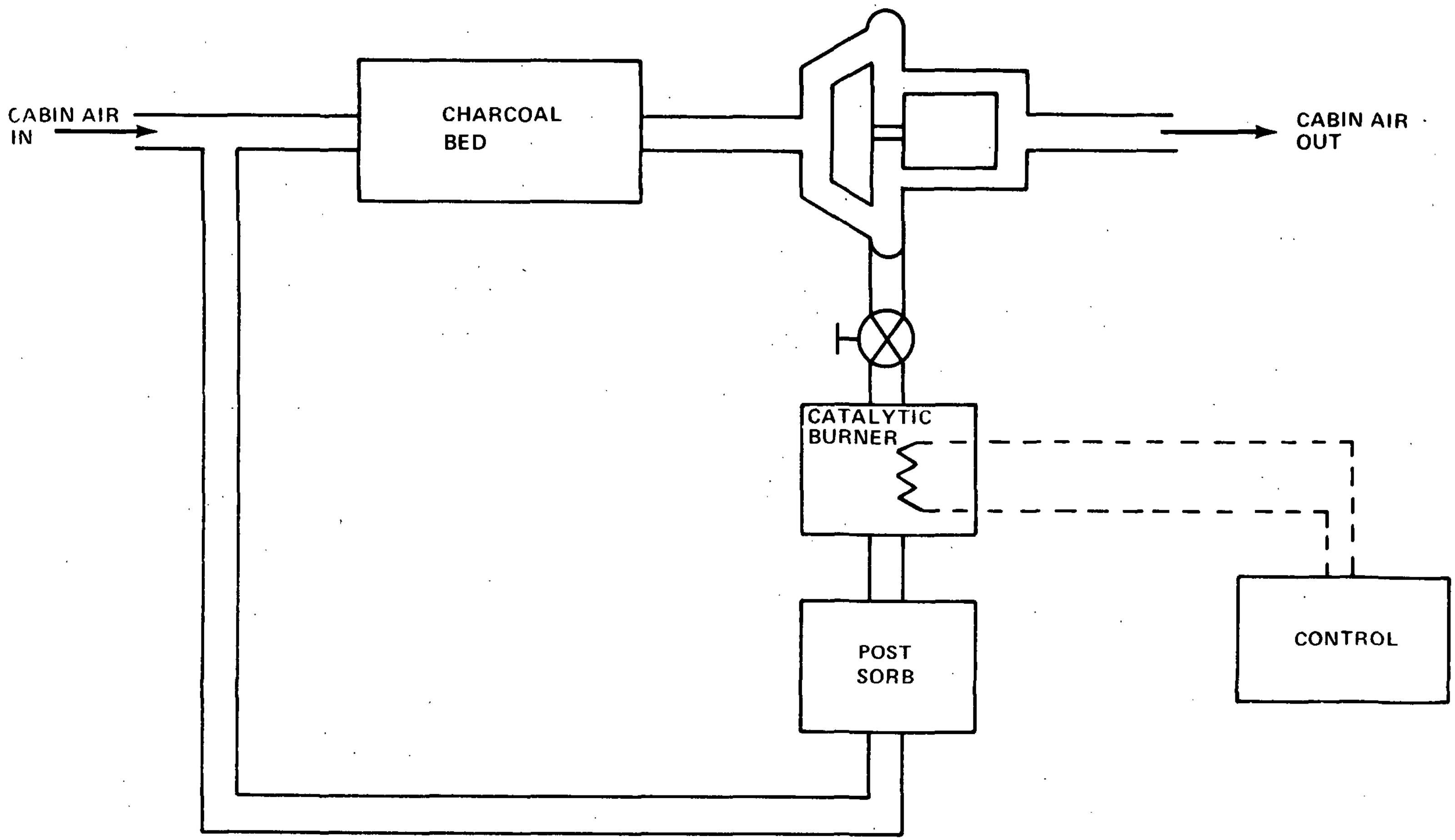

Figure 12. Nonregenerable charcoal concept.

TABLE 23. NONREGENERABLE CHARCOAL/CATALYTIC OXIDATION ASSEMBLY DETAILED MASS BREAKDOWN (THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Fan	1	0.59	1.3
Charcoal Bed	1	1.36	3.0
Manual Shutoff Valve	1	0.54	1.2
Catalytic Burner	1	4.72	10.4
Post-sorbent Bed	1	0.45	1.0
Heater Controller (Catalytic Burner)	1	1.36	3.0
Installation Hardware	1	2.77	6.1
Total		11.79	26.0

a. Conversion factor: 2.205 lb/kg.

An open water loop is utilized for the 30-day Shuttle module animal colony. Since the waste water is not reclaimed, contaminants and bacteria growth in the water should present no problem. A simple water management assembly for the open loop might consist of a water storage tank, a water chiller, pump, filter, gages, valves, and plumbing. This assembly as tabulated in Table 25 would weigh about 16 kg (35.3 lb).

Water reclamation techniques are recommended for the laboratory and centrifuge colonies. Partial closure of the water loop can be accomplished by reclaiming the condensate or urine water of the animals. The best possible choices appear to be air evaporation for urine recovery and multifiltration for condensate recovery. These assemblies, which were used in the Modular Space Station effort, underwent the 90-day test in the McDonnell-Douglas simulator. The multifiltration process is simple, requires very low power, and is inexpensive. Figures 13 and 14 illustrate the assemblies, and Tables 26 and 27 give detailed mass breakdowns for a three-man capacity. Three such assemblies must be interconnected to provide the nine-man capacity needed.

TABLE 24. 30-DAY SHUTTLE MODULE WATER BALANCE
(32 WHITE RATS AND 2 MACAQUE MONKEYS)

	Mass, kg	Weight,[a] lb
Water Input		
Drinking Water (0.29 kg/monkey-day)	0.58	1.279
Water of Oxidation (0.05 kg/monkey-day)	0.10	0.220
Drinking Water (0.0487 kg/rat-day)	1.558	3.435
Water of Oxidation (0.0091 kg/rat-day)	0.291	0.642
Total Required	2.529	5.576
Water Output		
Urine Water (0.22 kg/monkey-day)	0.44	0.970
Perspiration and Respiration (0.12 kg/monkey-day)	0.24	0.529
Urine Water (0.0203 kg/rat-day)	0.649	1.431
Perspiration and Respiration (0.0375 kg/rat-day)	1.200	2.646
Total Required	2.529	5.576

a. Conversion factor: 2.205 lb/kg.

SECTION VIII. ANIMAL WASTE MANAGEMENT ASSEMBLY

The waste management assemblies for the 30-day Shuttle module, laboratory, and centrifuge animal colonies should be very similar in certain respects to those for men. The two-man waste management assembly for the Shuttle crew compartment should be more than adequate to handle the animal wastes for the 30-day Shuttle module colony. The laboratory and centrifuge

TABLE 25. WATER MANAGEMENT ASSEMBLY MASS BREAKDOWN (TWO-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
H_2O Tank	1	6.00	13.23
Pump	1	1.80	3.969
Chiller	1	0.91	2.007
Filter	1	2.36	5.204
Gages, Valves, Plumbing, etc.	?	5.00	11.03
Total		16.07	35.44

a. Conversion factor: 2.205 lb/kg.

animal wastes will utilize a modified version of the integrated vacuum drying assembly selected for the Option IV Modular Space Station.

The handling of the animal feces and urine may prove to be one of the most difficult zero-g problems. It is very unlikely that the animals can be "toilet" trained; therefore the waste management system must provide adequate separation of the waste materials without animal cooperation. In the zero-g state, there is no settling force so other techniques must be utilized. Perhaps the most meaningful force is that of air movement. Since air must be circulated for other purposes, it is attractive for use here.

Air motion and aerodynamic drag on particulate matter is one method considered for sweeping the cages clear of feces and debris along with the urine. Examples of the air motion method are described in References 3 and 4. It is assumed that the animals will soon learn to face upstream when defecating and urinating. Further study is necessary on animal position for waste removal. Screen wires could be provided at the rear and on one side of the cage so that the rats or monkeys can cling to the screen and move along the side and rear of the cage. The solid wastes and liquid urine are collected and retained on waste pads located at one end of the cage. Previous studies have indicated that the waste pads should be capable of retaining a 45-day or more output of fecal matter without attention. The humidity-control system will be

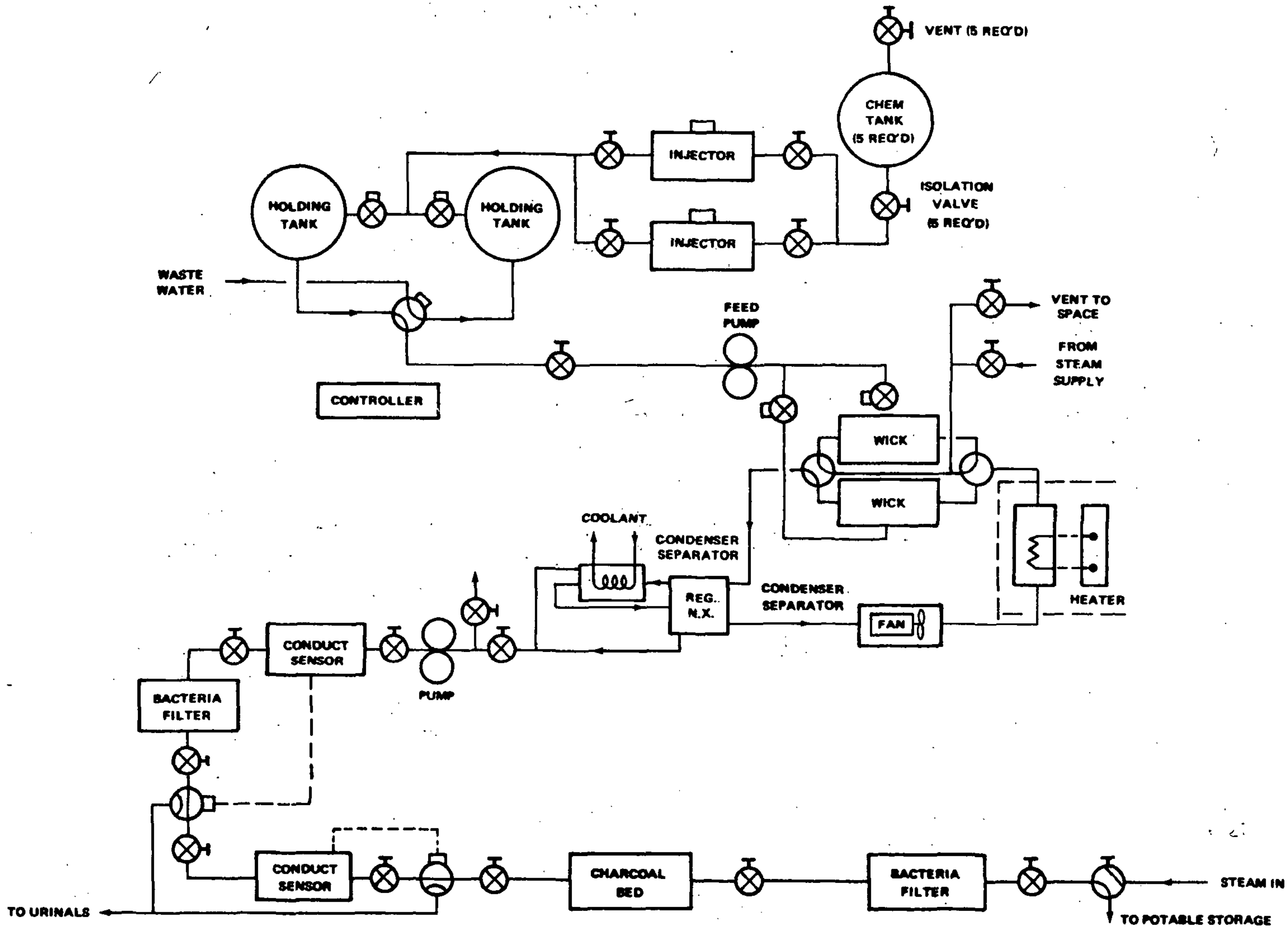

Figure 13. Closed cycle air evaporation concept.

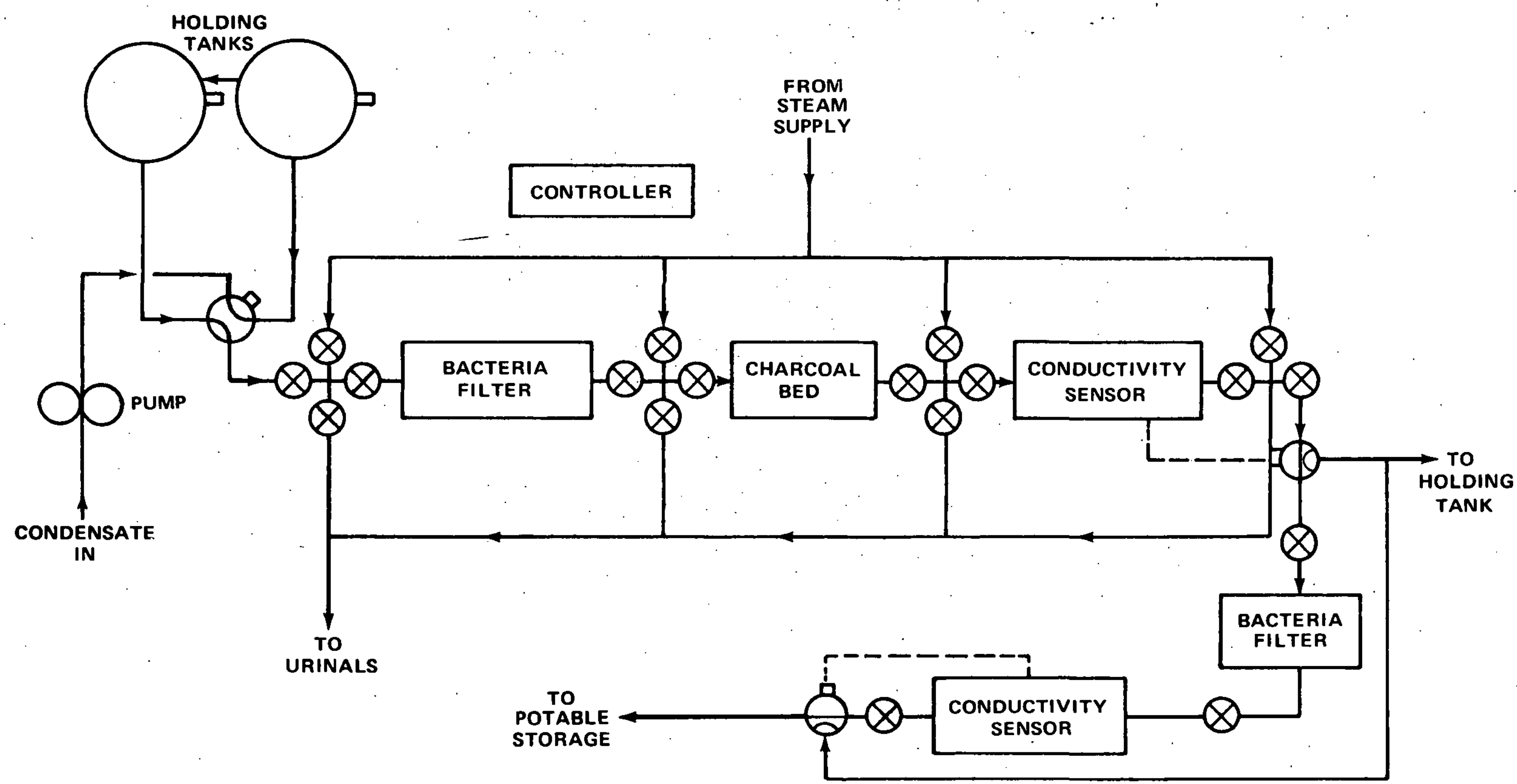

Figure 14. Multifiltration concept.

TABLE 26. AIR EVAPORATION ASSEMBLY
DETAILED MASS BREAKDOWN
(THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Chemical Storage Tank Connector	2	0.45	1.0
Pre-treat Tank	2	3.9	8.6
Manual, Three-way Valve	1	0.23	0.5
Evaporator	2	6.8	15.0
Condenser/Separator	1	3.4	7.5
Manual, Four-way Valve	2	0.05	0.1
Fan	1	0.68	1.5
Heater	1	0.68	1.5
Heater Control	1	0.82	1.8
Charcoal Filter Canister	1	0.82	1.8
Chemical Injector	2	3.27	7.2
Solenoid, Four-way	1	0.45	1.0
Solenoid, Three-way	1	0.32	0.7
Shutoff Valve	17	1.95	4.3
Feed Valve	4	0.91	2.0
Pumps	2	1.36	3.0
Controller	1	1.36	3.0
Conductivity Sensor	1	1.27	2.8
Heat Exchanger	1	3.17	7.0
Bacteria Filter	1	1.18	2.6
Controls		1.22	2.7
Structure		1.81	4.0
Plumbing		2.27	5.0
Wiring		0.91	2.0
Total		39.28	86.6

a. Conversion factor: 2.205 lb/kg.

TABLE 27. MULTIFILTRATION ASSEMBLY DETAILED MASS BREAKDOWN (THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Diverter Valve, Four-way	1	0.82	1.8
Multifiltration Bed	1	0.82	1.8
Bacteria Filter	2	1.63	3.6
Conductivity Sensor	1	0.54	1.2
Solenoid Valve, Three-way	1	0.82	1.8
Pump	1	0.68	1.5
Manual Shutoff Valve	6	0.82	1.8
Controller	1	0.68	1.5
Total		6.81	15.0

a. Conversion factor: 2.205 lb/kg.

designed to maintain a relatively dry atmosphere in the cages so that the fecal matter will dry without excessive decomposition. Provisions for replacement or cleaning the pads with a small vacuum cleaner can be made if necessary. Urine is held by the pads until it evaporates and is removed by the LiCl desiccant in the humidity control system.

The urine and condensate from the laboratory and centrifuge colonies may be excessive enough to employ urine recovery equipment. This involves collecting the urine in liquid form and transferring it to the water management assembly for recovery processing. Urine water and condensate produced by the 30-day Shuttle module colony will be dumped overboard. During periods of nondumping the liquid wastes can be dumped into a storage tank. Fecal wastes are collected in waste collection bags and placed in a storage container, which will be transported back to earth via Shuttle. A modified waste management assembly used in the Shuttle crew compartment is a good candidate for this module. A detailed mass breakdown of the assembly, which weighs 43 kg (95 lb), is listed in Table 28. A modified version of the integrated vacuum drying concept, which was used in the Modular Space Station, is a suitable approach for the waste management in the laboratory and centrifuge colonies. It has been tested in the 60- and 90-day tests of MDAC's Space Station simulator. This concept was selected for the Modular Space Station because of the low development risks, least overall cost, and crew acceptability.

TABLE 28. SHUTTLE CREW COMPARTMENT WASTE MANAGEMENT ASSEMBLY DETAILED MASS BREAKDOWN (TWO-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Urinal Cover	1	0.59	1.3
Fan (Urinal)	2	3.63	8.0
Fan (Odor Control)	2	3.18	7.0
Sterilizer (Ag Cl)	1	1.04	2.3
Urine and Air Separator	1	2.27	5.0
Bacteria Filter and Motor	1	2.27	5.0
Water Separator (Urine, Solids and Liquids)	1	1.81	4.0
Storage Tanks		6.35	14.0
Charcoal Bed	1	1.95	4.3
Toilet	1	6.80	15.0
Air Filter	1	0.23	0.5
Collection Bags		2.72	6.0
Installation, Insulation, etc.		9.07	20.0
Contingency		1.18	2.6
Total		43.09	95.0

a. Conversion factor: 2.205 lb/kg.

The manned integrated vacuum drying assembly consists of a seat, replaceable liner, rotary deflector, blower, a vacuum vent line, an atmosphere recovery line, controls, selector valves, and appropriate filters. The concept is shown pictorially in Figure 15 and a detailed mass breakdown of a three-man assembly is depicted in Table 29.

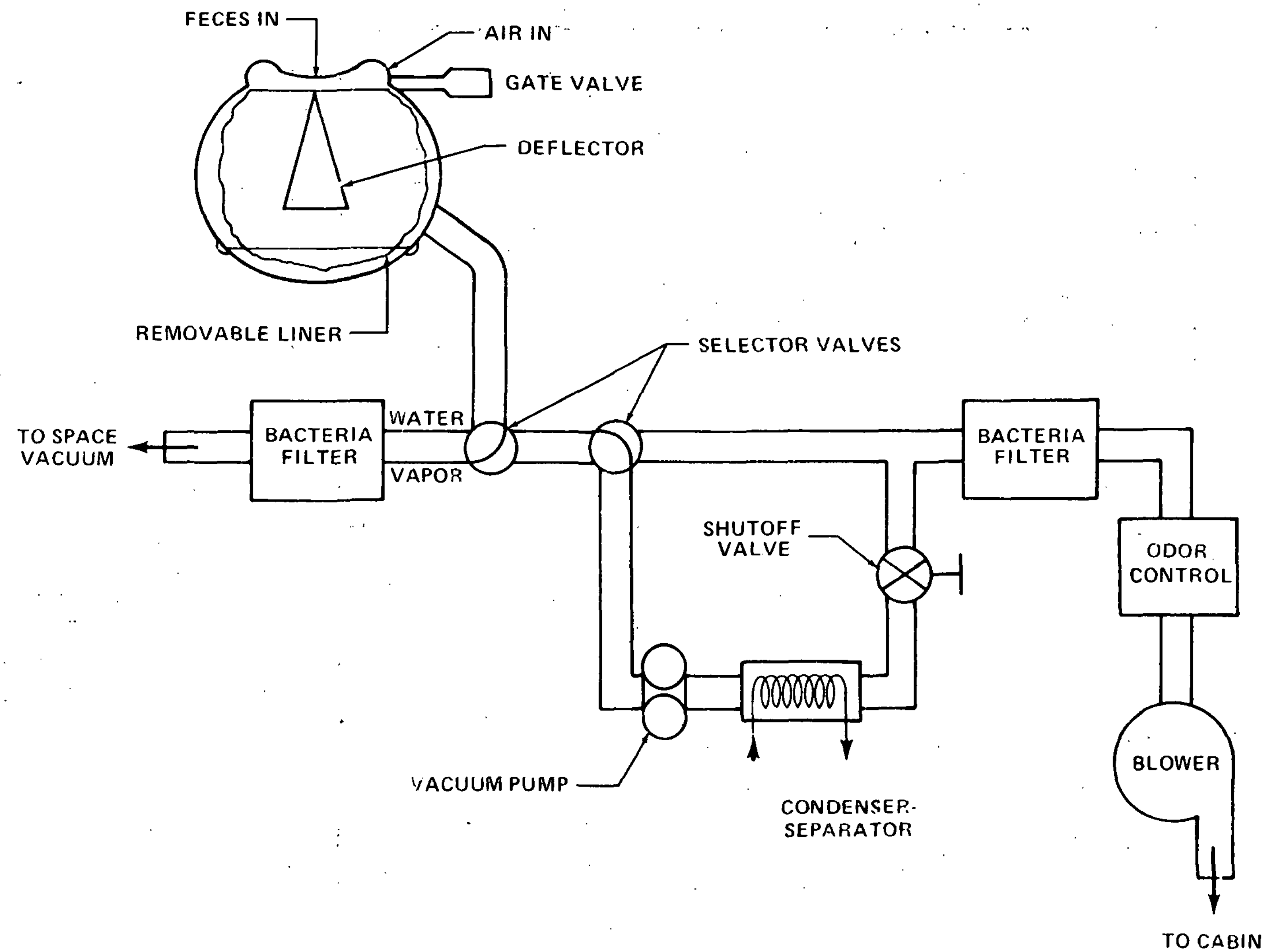

Figure 15. Manned integrated vacuum drying/storage concept.

TABLE 29. INTEGRATED VACUUM DRYING ASSEMBLY MASS (THREE-MAN EC/LSS)

Component	No. Required	Mass, kg	Weight,[a] lb
Waste Collector	1	2.72	6.0
Slinger Motor	1	0.91	2.0
Shredder	1	9.07	20.0
Heater Control	2	0.64	1.4
Process Flow Fan	1	0.91	2.0
Urinal	1	1.36	3.0
Cycle Control	1	1.13	2.5
Urine/Air Separator	1	0.91	2.0
Urine Pump	1	0.23	0.5
Bacteria Filter	2	0.18	0.4
Odor Removal Filter	1	0.23	0.5
Solenoid Shutoff Valve	3	3.81	8.4
Check Valve	3	0.68	1.5
Pressure Switch		0.23	0.5
Vacuum Pump		0.27	0.6
Manual Shutoff Valve	4	0.91	2.0
Heater	1	0.91	2.0
Structures and Installation		4.54	10.0
Miscellaneous		4.54	10.0
Total		34.18	75.3

a. Conversion factor: 2.205 lb/kg.

SECTION IX: ANIMAL EXPENDABLE REQUIREMENTS

Food and oxygen expendables for the 30-day Shuttle module, laboratory, and centrifuge animal colonies are approximately equal to those of their 1-, 7-, and 9-man equivalents, respectively. The centrifuge colony of 352 rats, 2 Macaque monkeys, and 1 chimpanzee consumes approximately the same mass of food and oxygen that 9 men would require in orbit. Considerably much more metabolic water is required for the men than the animals on these missions. The laboratory and centrifuge consumables will impose large penalties on the launch and resupply vehicles. For example, the centrifuge colony mentioned

above requires 851 kg (1877 lb) of metabolic oxygen, 2717 kg (5991 lb) of water, and 909 kg (2004 lb)[2] of food for a 90-day mission.

Sufficient quantities of oxygen and nitrogen must be maintained on board the experiment module to sustain the animal colonies between resupply periods. For the laboratory and centrifuge colonies, this amounts to a normal 90-day supply plus a 30-day contingency for emergency metabolic and leakage needs. Cryogenic consumables (O_2 and N_2) are required for various activities such as metabolic and leakage purposes, initial and emergency pressurizations, maintainability losses, and reserves. These activities, as reflected in Table 30, require approximately 71 kg (157 lb) of oxygen and 110 kg (243 lb) of nitrogen for the 30-day Shuttle module. Tables 31 and 32 show the oxygen and nitrogen requirements for the laboratory and centrifuge colonies. The amount of oxygen for the laboratory and centrifuge payloads is approximately 758 kg (1671 lb) and 975 kg (2150 lb), respectively. The required nitrogen is approximately 298 kg (657 lb) in each case.

Summaries of the expendable masses plus containers for the 30-day Shuttle module, the laboratory, and centrifuge colonies are shown in Tables 33, 34, and 35. These total 218 kg (464 lb), 4422 kg (9750 lb), and 5580 kg (12 303 lb), respectively. Included are oxygen, nitrogen, water, food, and containers for the rats, monkeys, and chimpanzees.

2. All figures cited in this example include a 30-day reserve.

TABLE 30. ONBOARD OPEN LOOP CONSUMABLES AT SHUTTLE INITIAL LAUNCH (32 WHITE RATS AND 2 MACAQUE MONKEYS)

	Fluid Mass and Weight			
	O_2		N_2	
	kg	lb[a]	kg	lb[a]
Module Leakage (30 days)	2.90	6.4	10.71	23.6
Module Leakage Reserve (30 days)	2.90	6.4	10.71	23.6
Rat Metabolic Oxygen (30 days)	17.28	38.1		
Rat Metabolic Oxygen Reserve (30 days)	17.28	38.1		
Monkey Metabolic Oxygen (30 days)	3.12	6.9		
Monkey Metabolic Oxygen Reserve (30 days)	3.12	6.9		
Initial Module Pressurization	9.07	20.0	34.01	75.0
Emergency Module Pressurization	9.07	20.0	34.01	75.0
Initial Airlock Pressurization	0.91	2.0	2.72	6.0
Emergency Airlock Pressurization	0.91	2.0	2.72	6.0
Molecular Sieve Ullage	2.80	6.2	10.48	23.1
Gas Losses for Maintainability	6.44	14.2	24.23	53.4
Contingency	3.79	8.4	14.26	31.4
Overall Requirements	79.59	175.6	143.85	317.1
Less Initial Pressurization Gases	-9.07	-20.0	-34.01	-75.0
Total Cryogen Storage	70.52	155.6	109.84	242.1

a. Conversion factor: 2.205 lb/kg.

TABLE 31. ONBOARD OPEN LOOP CONSUMABLES AT INITIAL LAUNCH (LABORATORY ONLY) (256 WHITE RATS, 2 MACAQUE MONKEYS, AND 1 CHIMPANZEE)

	Fluid Mass and Weight			
	O_2		N_2	
	kg	lb[a]	kg	lb[a]
Module Leakage (90 days, 0.454 kg/day)	8.62	19.0	32.20	71.0
Module Leakage Reserve (30 days)	2.72	6.0	10.88	24.0
Rat Metabolic Oxygen (90 days)	415.00	915.1		
Rat Metabolic Oxygen Reserve (30 days)	138.32	305.0		
Monkey Metabolic Oxygen (90 days)	9.52	21.0		
Monkey Metabolic Oxygen Reserve	3.18	7.0		
Chimpanzee Metabolic Oxygen (90 days)	59.00	130.1		
Chimpanzee Metabolic Oxygen Reserve (30 days)	19.50	43.0		
Initial Module Pressurization	9.07	20.0	34.01	75.0
Emergency Module Pressurization	9.07	20.0	34.01	75.0
Initial Airlock Pressurization	0.91	2.0	2.72	6.0
Emergency Airlock Pressurization	0.91	2.0	2.72	6.0
Molecular Sieve Ullage	38.55	85.0	141.04	311.0
Gas Losses for Maintainability	15.87	35.0	58.5	129.0
Contingency	36.73	81.0	15.87	35.0
Overall Requirements	766.97	1691.2	331.95	732.0
Less Initial Pressurization Gasses	-9.07	-20.0	-34.01	-75.0
Total Cryogen Storage	757.90	1671.2	297.94	657.0

a. Conversion factor: 2.205 lb/kg.

TABLE 32. ONBOARD OPEN LOOP CONSUMABLES AT INITIAL LAUNCH (CENTRIFUGE) (352 WHITE RATS, 2 MACAQUE MONKEYS, AND 1 CHIMPANZEE)

	Fluid Mass and Weight			
	O_2		N_2	
	kg	lb[a]	kg	lb[a]
Module Leakage (90 days, 0.454 kg/day)	8.62	19.0	32.20	71.0
Module Leakage Reserve (30 days)	2.72	6.0	10.88	24.0
Rat Metabolic Oxygen (90 days)	570.07	1257.0		
Rat Metabolic Oxygen Reserve (30 days)	190.02	419.0		
Monkey Metabolic Oxygen (90 days)	9.52	21.0		
Monkey Metabolic Oxygen Reserve (30 days)	3.18	7.0		
Chimpanzee Metabolic Oxygen (90 days)	59.00	130.0		
Chimpanzee Metabolic Oxygen Reserve (30 days)	19.50	43.0		
Initial Module Pressurization	9.07	20.0	34.01	75.0
Emergency Module Pressurization	9.07	20.0	34.01	75.0
Initial Airlock Pressurization	0.91	2.0	2.72	6.0
Emergency Airlock Pressurization	0.91	2.0	2.72	6.0
Molecular Sieve Ullage	38.55	85.0	141.04	311.0
Gas Losses for Maintainability	15.87	35.0	58.5	129.0
Contingency	46.71	103.0	15.87	35.0
Overall Requirements	983.72	2169.0	311.95	732.0
Less Initial Pressurization Gasses	-9.07	-20.0	-34.01	-75.0
Total Cryogen Storage	974.65	2149.0	297.94	657.0

a. Conversion factor: 2.205 lb/kg.

TABLE 33. ONBOARD OPEN LOOP SHUTTLE EXPENDABLE MASS AND WEIGHT SUMMARY (30 DAYS) (32 WHITE RATS AND 2 MACAQUE MONKEYS)[a]

Expendable	Mass, kg	Weight,[c] lb
Rat Food (30 days)	19	42
Rat Food Reserve (30 days)	19	42
Monkey Food (30 days)	7	15
Monkey Food Reserve (30 days)	7	15
Animal H_2O (30 days)	76	168
Animal H_2O Reserve (30 days)	76	168
Animal O_2 (Metabolic)	41[d]	90[d]
O_2 Leakage, Pressurization, Reserve, etc.[b]	30[d]	66[d]
N_2 Leakage, Pressurization, Reserve, etc.[b]	110[d]	243[d]
Total	385	849

Containers for	Tank No.	Mass and Weight per Container		Total Container Mass and Weight		Total Container and Expendable	
		kg	lb	kg	lb	Mass, kg	Weight, lb
Animal Food	?	?		?		52	115
H_2O Tank	1	6	13.2	6	13.2	158	349
O_2 Cryogenic Tank[d]	0	0		0		0	
N_2 Cryogenic Tank[d]	0	0		0		0	
		Total		6	13.2	218	464

a. Open O_2 and H_2O Loop.
b. Leakage rate assumed to be 0.454 kg/day (1 lb/day) for Experiment Module.
c. Conversion factor: 2.205 lb/kg.
d. 71 kg (157 lb) O_2 and 110 kg (243 lb) N_2 contained in Shuttle cryogenic tanks.

TABLE 34. ONBOARD OPEN LOOP EXPENDABLE MASS AND WEIGHT SUMMARY (LABORATORY ONLY) (256 WHITE RATS, 2 MACAQUE MONKEYS, 1 CHIMPANZEE)[a]

Expendable	Mass, kg	Weight,[c] lb
Rat Food (90 days)	461	1017
Rat Food Reserve (30 days)	154	340
Monkey Food (90 days)	22	49
Monkey Food Reserve (30 days)	7	15
Chimpanzee Food (90 days)	26	57
Chimpanzee Food Reserve (30 days)	9	20
Animal H_2O (90 days)	1538	3391
Animal H_2O Reserve (30 days)	513	1131
Animal O_2 (Metabolic)	645[d]	1422[d]
O_2 Leakage, Pressurization, Reserve, etc.[b]	113[d]	249[d]
N_2 Leakage, Pressurization, Reserve, etc.[b]	298[d]	657[d]
Total	3786	8348

Containers for	Type and Size	No.	Mass and Weight per Container		Total Container Mass and Weight		Total Container and Expendable	
			kg	lb	kg	lb	Mass, kg	Weight, lb
Animal Food	?	?	?	?	?	?	679	1497
H_2O	New Tanks (101.6 cm I. D.)	4	45	99	180	397	2231	4919
O_2 Cryogenic	AAP Type (99.06 cm I. D.)	2[d]	152	335	304	670	1062	2342
N_2 Cryogenic	AAP Type (99.06 cm I. D.)	1[d]	152	335	152	335	450	992
			Total		636	1402	4422	9750

a. Open O_2 and H_2O Loop.
b. Leakage rate assumed to be 0.454 kg/day (1 lb/day) for Experiment Module.
c. Conversion factor: 2.205 lb/kg.
d. 330 kg (728 lb) of O_2 and 87 kg (192 lb) of N_2 can be added for tank capacity.

TABLE 35. ONBOARD OPEN LOOP EXPENDABLE MASS AND WEIGHT SUMMARY (CENTRIFUGE ONLY) (352 WHITE RATS, 2 MACAQUE MONKEYS, AND 1 CHIMPANZEE)[a]

Expendable	Mass, kg	Weight,[c] lb
Rat Food (90 days)	634	1398
Rat Food Reserve (30 days)	211	465
Monkey Food (90 days)	22	49
Monkey Food Reserve (30 days)	7	15
Chimpanzee Food (90 days)	26	57
Chimpanzee Food Reserve (30 days)	9	20
Animal H_2O (90 days)	2038	4494
Animal H_2O Reserve (30 days)	679	1497
Animal O_2 (Metabolic)	851[d]	1877[d]
O_2 Leakage, Pressurization, Reserve, etc.[b]	124[d]	273[d]
N_2 Leakage, Pressurization, Reserve, etc.[b]	298[d]	657[d]
Total	4899	10 802

Containers for	Type and Size	No.	Mass and Weight per Container		Total Container Mass and Weight		Total Container and Expendable	
			kg	lb	kg	lb	Mass, kg	Weight, lb
Animal Food	?	?	?	?	?	?	909	2004
H_2O	New Tanks (101.6 cm I. D.)	5	45	99	225	495	2942	6487
O_2 Cryogenic	AAP Type (99.06 cm I. D.)	2[d]	152	335	304	670	1279	2820
N_2 Cryogenic	AAP Type (99.06 cm I. D.)	1[d]	152	335	152	335	450	992
			Total		681	1500	5580	12 303

a. Open O_2 and H_2O Loop.
b. Leakage rate assumed to be 0.454 kg/day (1 lb/day) for Experiment Module.
c. Conversion factor: 2.205 lb/kg.
d. 250 kg (551 lb) of O_2 and 87 kg (192 lb) N_2 can be added for tank capacity.

REFERENCES

1. Wells, Hubert B. and Kromis, Andrew G.: Environmental Control and Life Support Subsystem (EC/LSS) for the Modular Space Station (Option IV). NASA TM X-64603, February 15, 1971.

2. Preliminary Edition of Reference Earth Orbital Research and Applications Investigations (Blue Book). Volume VIII, Life Sciences, National Aeronautical and Space Administration, January 15, 1971.

3. Study of an Animal Research Facility (Using S-IVB) for a Manned Orbital Biotechnology Laboratory. Final Report, DAC - 58039, Contract NAS7-518, Douglas Aircraft Corporation, September 1967.

4. Russ, E.J.: A Study of Environmental Control and Life Support Systems for Spacecraft Animal Experiments. General Dynamics Corporation (Convair Division), Report GDC-ERR-1401, Contract NAS8-25051, December 31, 1969.

5. Altman, P. L. and Dittmer, D.S.: Metabolism. Federation of American Societies for Experimental Biology, Bethesda, Maryland, 1968.

6. Altman, P.L. and Dittmer, D.S.: Biology Data Book. AMRL-TR-64-100, October 1964.

7. Bioastronautics Data Book. NASA SP-3006.

8. Preliminary Results from an Operational 90-day Manned Test of a Regenerative Life Support System. NASA SP-261, November 17-18, 1970.

9. Mechtly, E.A.: The International System of Units. NASA SP-7012.

APPROVAL

A PRELIMINARY INVESTIGATION OF THE ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEMS (EC/LSS) FOR ANIMAL AND PLANT EXPERIMENT PAYLOADS

By Hubert B. Wells

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Andrew G. Kromis

ANDREW G. KROMIS
Chief, Crew Systems Branch

Jay H. Laue

JAY H. LAUE
Deputy Chief, Propulsion and Mechanical Systems Division

Herman E. Thomason

ERICH E. GOERNER
Director, Preliminary Design Office

James T. Murphy

JAMES T. MURPHY
Director, Program Development

☆ U.S. Government Printing Office: 1972 — 745-386/4124 Region No. 4

DISTRIBUTION

INTERNAL

DIR
Dr. Rees

DEP-T
Dr. Lucas

AD-S
Dr. Stuhlinger

PD-DIR
Mr. Murphy
Dr. Mrazek
Mr. Downey

PD-RV
Mr. Godfrey
Mr. Jean
Mr. McCool
Mr. Thomson
Mr. Corcoran

PD-MP-DIR
Mr. Gierow

PD-MP-S
Mr. May
Dr. Hilchey

PD-MP-T
Mr. Carey

PD-PP-DIR
Mr. Sneed

PD-RAM
Mr. Zoller

PD-PS-DIR
Mr. Goodrum
Mr. Stein

PD-PS-T
Mr. Tidd

PD-SA-DIR

Mr. Huber/Spears

PD-SA-L
Mr. Sharpe

PD-SA-O
Mr. von Tiesenhausen
Mr. Cramblit
Mr. Thompson

PD-SA-P
Mr. Harris

PD-SA-V
Mr. Orillion/Barrett

PD-DO-DIR
Mr. Goerner
Dr. Thomason
Mr. Heyer
Mrs. Andrews

PD-DO-S
Mr. Marshall
Mr. Darwin
Mr. Wales
Mr. Perkins

PD-DO-SA
Mr. Denton

PD-DO-P
Mr. Allen
Mr. Sparks

PD-DO-SL
Mr. Blumrich
Mr. Black

PD-DO-SI
Mr. Shelton
Mr. Wicks
Mr. Peoples

PD-DO-E
Mr. Digesu
Mr. Harden
Mr. Brantley
Mr. Giudici

PD-DO-M
Mr. Laue
Mr. Nixon

PD-DO-MP
Mr. Sanders
Mr. Schwartz
Mr. Thompson

PD-DO-MC
Mr. Kromis
Mr. Weaver
Mr. Wells (25)
Mr. Johanson
Mrs. Dembrosky

PD-DO-P
Mr. Goldsby

PD-SA-DIR
Mr. Ellsworth

PD-SS-MGR
Mr. Brooksbank
Mr. Dannenberg

PD-SS-S
Mr. Palaoro

PD-SS-T
Mr. Keller

PD-SS-M
Mr. Lavender

PD-SS
Mr. Bramlet

PD-SS-S
Mr. Pedigo

PD-SS-M
Mr. Barr

PM-AA-MGR
Mr. Belew

PM-EP-P
Mr. Thomas

PM-PR-M
Mr. Stevens

S&E-ASTN-P
Mr. Wood

S&E-ASTN-PL
Mr. Hopson

S&E-ASTN-PT
Mr. Cody

S&E-ASTN-PLB
Mr. Middleton

S&E-CSE-S
Mr. Aberg

A&TS-MS-D
Mr. Garrett

A&TS-TU-DIR
Mr. Wiggins

A&TS-MS-I
Mr. Remer

A&TS-MS-IP
Mr. Ziak (2)

A&TS-MS-IL
Miss Robertson (8)

A&TS-MS-H
Mr. Akens

A& TS-PAT
Mr. Wofford

A&TS-TU (6)

Scientific and Technical Information Facility
College Park, Maryland 20740
Attn: NASA Representative (S-AK/RKT) (25)